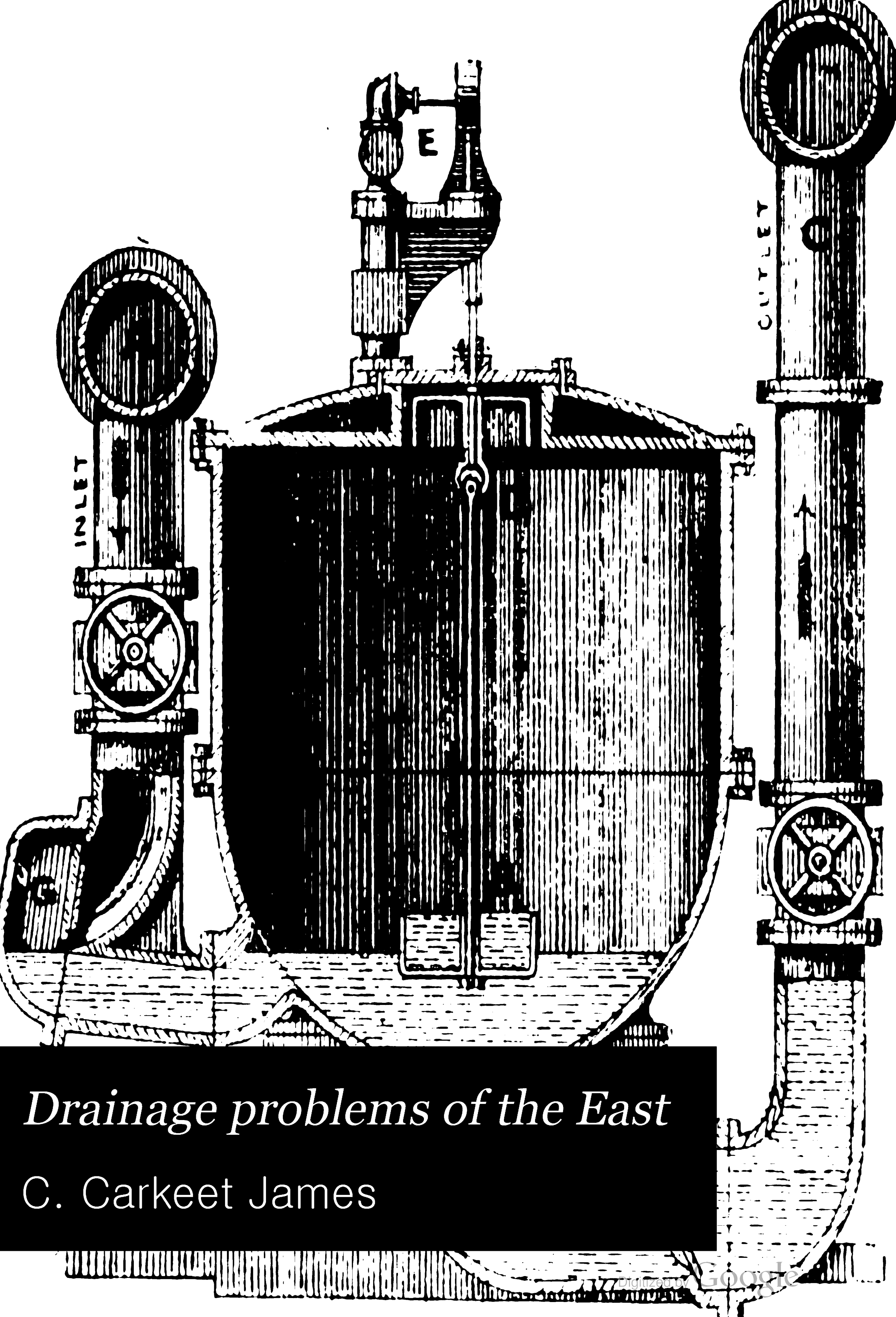

Drainage problems of the East

C. Carkeet James

DRAINAGE PROBLEMS
OF THE EAST.

DRAINAGE PROBLEMS OF THE EAST:

BEING A REVISED AND ENLARGED EDITION OF
"ORIENTAL DRAINAGE:"

BY

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PREFACE.

The favourable reception that has been accorded to my *Oriental Drainage* by the profession and the Municipal and Sanitary Authorities, as well as by a large section of the general public, encouraged me to contemplate the issue of another edition. In making preparations, however, with that object in view, I found that there was so much new and valuable matter of a practical and interesting nature that might with advantage be included in a new work, and that the original volume was susceptible of considerable expansion in order the more thoroughly to extend the scope of the work, that nothing short of a new book would meet the requirements of the subject. The many changes thus involved in the extent and nature of the original work have caused me to adopt the name *Drainage Problems of the East* in order to distinguish the present work from its predecessor, from which, though fundamentally similar, it differs very much both in its scope and in its text, as well as by the plans and illustrations which form, I hope, not its least interesting feature.

Apart from the bringing up to date and expansion of the Chapters taken from the original work, new Chapters have been added, dealing with such highly instructive drainage-systems as those of Karachi, Calcutta, Rangoon, Singapore, Penang, Shanghai, and Alexandria, which cover a wider geographical area, as well as with sanitary conditions in other Eastern countries and with some of the more important enterprises that have been undertaken in recent years in India and the Far East.

The development of the use of Septic Gas has also been fully dealt with, and with it the more recent experiments in regard to the biological treatment of sewage have been described.

New Appendices have been added, one dealing with useful and short specifications connected with sanitary matters, and the other giving a description of the Hydrolytic Tank designed by the eminent experts Dr. Owen Travis, M.D., M.S., Barrister-at-Law, and Mr. Edwin Ault, C.E.

I have to express my thanks to Mr. N. Maughan, A.M.I.C.E., and my Assistant Mr. Dinshaw D. Daruvala, A.M.I.C.E., L.C.E., who have given me much valuable help in the compilation of this work.

C. CARKEET JAMES.

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PART I.

INTRODUCTION.

Many standard works on Sewage Disposal and Drainage have been written, according to the practice prevailing in Western Countries, but so far none have appeared in regard to India and the East, although the need for some standard books for these countries has long been felt by Sanitary Engineers. Many short works have been published on various subjects connected with the question, but none have dealt with it as a whole. The Author proposes in the following pages to endeavour to supply that want and to incorporate in this work the experience obtained by him in practice during his extended connection with the Bombay City Sewerage System. The need of a treatise on "Oriental Drainage" is emphasized by the fact that in dealing with the Sanitation of an Eastern City, ideas and practices which may be wholly successful in Europe are not necessarily so in Asia. The main principles will probably be applicable both to East and West, but the details necessarily widely diverge, and to blindly accept in its entirety an English system is to court defeat in an Oriental City.

The prejudices and habits of the people are in many ways opposed to an English system of drainage, while the climate renders the quicker removal of excrementitious matter a paramount necessity. We must also remember that Orientals use more water for washing purposes than their brethren in Europe, principally on account of frequent religious ceremonies involving ablutions.

The habit, which obtains with almost all Orientals, of scouring their domestic metal utensils with ashes, sand, or road detritus, adds largely to the possibility of chokage in sewers. These substances when mixed with fæcal matter form a kind of concrete, the removal of which is beset with much difficulty.

The climatic conditions of a tropical country add many difficulties to the satisfactory solution of Drainage Problems, the temperature being generally such that putrefaction rapidly takes place. A high temperature causes an excessive formation of gas in sewers, and the introduction of sewage-gas into dwellings means disease. Consequently special consideration has to be given to the ventilation of sewers and to the materials used in the construction of sewerage works. The temperature of the ground is also a consideration, and where the range is great, even stoneware pipes are susceptible to it. In many Indian Cities the range is very great, in some extending from below freezing point to above 110°. In Bombay, which is a singularly equable climate for India, the extreme maximum temperature of air observed during the last 50 years was 100·2° and the extreme minimum 53·°, but the ground temperature varies little. The temperature of the water supply probably decides that of the sewage and is also generally that of the sub-soil water.

The gradients of sewers which are considered in Europe to give sufficient velocity for the removal of solids are, as will be shewn hereafter, insufficient in India. There is, too, the additional disadvantage, as before pointed out, of the presence of materials used for cleansing domestic utensils, as well as the fact that public and private latrines have to deal with quantities of stones, broken tiles, and rags, much of which find their way into the public sewers.

The ancient practice of building houses in Indian Cities so close together as to be detached only in name,

adds enormously to the difficulties of house-drainage, as also the fact that nearly all Hindu castes use dry leaves for plates, which are disposed of, some by being thrown into the washing-places which exist in the corners of most rooms, and some into the narrow *gullies* or passages which lie between the houses, whence they find their way into the house-drains.

Rainfall is a considerable factor in dealing with sewage. The rainfall of India varies in places from 600 inches per annum to nothing; but the fall in Bombay is fairly regular, as will be seen by the following figures, obtained from the Colaba Observatory, which give the annual rainfall from 1843 to 1905, inclusive:—

	Inches.		Inches.		Inches
1843	55·24	1864	45·56	1885	67·91
1844	62·71	1865	77·85	1886	99·74
1845	54·12	1866	78·44	1887	94·95
1846	73·93	1867	62·30	1888	57·82
1847	76·00	1868	62·12	1889	67·84
1848	75·86	1869	91·66	1890	65·18
1849	114·89	1870	66·21	1891	77·18
1850	50·25	1871	40·58	1892	95·42
1851	96·07	1872	76·48	1893	67·24
1852	69·27	1873	69·70	1894	66·85
1853	62·60	1874	82·18	1895	67·59
1854	82·14	1875	83·09	1896	87·65
1855	41·18	1876	50·04	1897	81·53
1856	65·92	1877	69·89	1898	74·09
1857	51·27	1878	111·93	1899	35·90
1858	62·45	1879	61·40	1900	69·12
1859	77·16	1880	67·94	1901	75·32
1860	62·15	1881	73·04	1902	71·97
1861	79·91	1882	69·23	1903	84·49
1862	73·63	1883	90·18	1904	33·42
1863	77·68	1884	75·44	1905	33·66

The maximum rainfall registered in any one day in these years was 16·10 inches—on the 18th June, 1886—and the greatest fall in an hour 4·22 inches. Rain in Bombay occurs on an average upon 104 days per annum. During heavy rain the evaporation in Bombay is small, but there

is no doubt that at other times it is great. Mr. Baldwin Latham, in his report on *The Sanitation of Bombay*, gives it at as much as 62 inches per annum, this figure being determined by calculations based on temperature, dryness of the air, and velocity of the wind. Some years ago Mr. David Gostling, F.R.I.B.A., made some observations in Bombay during twelve consecutive months and found the evaporation to be 51 inches for the whole year. This, however, might have been an exceptional year and does not necessarily disprove the correctness of Mr. Baldwin Latham's estimate.

Of the rain which falls in Bombay, with its large number of buildings, paved spaces, and metalled roads, the greater portion at once flows off, and the amount which percolates into the ground, according to Mr. Baldwin Latham, does not exceed on the average nine inches during the monsoon.

House-connections in an Indian City are always a matter for grave consideration, because under no circumstances can they be installed satisfactorily at a small cost, and because of the generally cheaper construction of buildings in the East than in the West and the consequent disproportion which often exists between the cost of a building and of its connections. Cases have occurred where the cost of a house-connection has exceeded the value of the building concerned.

Experience of Bombay teaches that the house-drain should, if possible, be an open drain; for open drains, though not cheaper than closed drains, have the advantage of being easily cleaned and generate no sewage gas.

A fact which cannot be too strongly insisted on and may be considered an axiom in Sanitary Science, is that a water-supply should not be brought into a town, unless efficient arrangements have been made for its removal immediately it has served its purpose: and if this

applies to the West, how much more should it apply to the East with its increased temperature?

The following is not an unfair description of many a mofussil town in India: A confined area, teeming with a dense population, the houses huddled together along narrow alleyways rather than streets; with few latrines and with very little attempt at sweeping, the refuse being generally taken no further than the nearest open space and the sewage finding its way to a convenient tank or soaking into the ground. In such circumstances the problem of a complete and satisfactory drainage scheme is by no means easy to solve.

The Author, however, hopes that the effort made in that direction in the following pages will be of use to Engineers in dealing with such problems.

DRAINAGE PROBLEMS OF THE EAST.

CHAPTER I.

DRAINAGE SYSTEMS.

UNTIL comparatively recent years, open drains at the sides of streets, that depended on the monsoon rains for their annual cleansing, constituted the only drainage system existing in many important Indian towns and cities, and no serious attempt had ever been made to deal effectively with the drainage of such areas.

By the passing of Municipal Acts, Government created local authorities with full powers to deal with the sanitation of their respective towns, and to compel the people themselves to adopt such sanitary measures as might be considered necessary for the general welfare of the inhabitants. It is, however, only of late years—owing chiefly to the ravages of enteric, plague, and other diseases in some of the largest urban areas—that these local authorities have realized their responsibilities in the matter, and that the people generally have awakened to a sense of the comfort and the benefits derivable from modern sanitary measures. The result has been that most of the larger cities and towns are now provided, or are about to be provided, with some modern arrangement for the disposal of their sewage, combined with a plentiful water supply.

Hand Removal or Conservancy System.—One of the earliest attempts of Municipal Government to deal with the sewage of towns was undoubtedly that of "hand removal," or as it is frequently named the "conservancy

system." This system still exists in many places possessed of no proper system of drainage, and may even be seen in those parts of Bombay City which have not as yet been connected with the main sewerage system.

Under the conservancy system, all night-soil, etc., is collected in vessels and deposited in local cess-pools provided for the purpose: the cess-pools are emptied periodically, the fœcal matter being carried away to some convenient site outside the inhabited area and buried in the ground, while the sullage is usually left to soak into the ground. In Bombay, cess-pools are cleared once in 24 hours, and their contents carried in closed iron carts to the nearest night-soil depot on the main sewerage system and discharged into the sewers.

There can be no question that this method is both objectionable and insanitary, in view (a) of the non-removal of sullage and fœces for several hours from the vicinity of buildings, (b) of the passage of sullage and night-soil carts through densely inhabited streets, and (c) of the emptying of these carts at various depots, and the consequent liberation of a large collection of offensive and dangerous gases. But the method is preferable to allowing refuse and filth of every description to putrify in the open air, and it is not every town that can afford to adopt a more modern method for the disposal of its sewage.

For use in connection with the working of the "conservancy system," many good types of native privies have from time to time been designed. Illustrations and descriptions of some of these are given in Chapter III.

Of the regular drainage systems followed, there are two kinds, known as the "combined" and "separate." The "combined system" is that in which all the sewage, stormwater, etc., are carried through one sewer. It is rarely applicable to Eastern countries, in which the seasons are well defined and the rainfall concentrated in practically

only four months of the year, for the reason that, where the rainfall exceeds 30 inches, no sewers have as yet been designed that are at once capable of being self-cleansing in the dry weather and large enough to carry the surface water during the monsoon period. Sewers of larger construction than are necessary for the sewerage proper, soon become charged with deposit in the dry weather and may thus prove highly injurious to health.

The "separate system" is that in which separate drains are provided for the sewage, the surface water, and occasionally the subsoil water. This system, though more costly than the "combined system," has three distinct advantages, namely: (a) smaller sewers can be used, (b) the formation of sewer gas is minimised, and (c) greater facilities are afforded for supervision and cleansing.

The Author's experience leads him to prefer carrying the subsoil and surface water in one drain, and all sewage and such rain water as falls on small court-yards and sweepers' passages or gullies in a separate sewer; and in spite of its extra cost, he believes this system to be generally the best suited to Eastern countries, in which the rainfall is confined to a few months in the year. No hard and fast rule for the adoption of any one system can, however, be laid down; the ultimate verdict must rest upon the fullest consideration of local conditions.

When once it has been decided which system should be adopted for the drainage of any area, a very careful study of the ground and its natural drainage should be undertaken, in order that the best alignment for the main sewers may be accurately determined and the most convenient and economical site chosen for the sewage outfall or place of discharge for final disposal.

Gravitation.—Sewers discharging wholly by gravitation into a river or sea are an ideal feature of any drainage system. In practice, however, the ideal is rarely

attainable; and it will generally be found necessary to lift the whole or a portion of the sewage of a town, either by pumping or other means, before it reaches its outfall and is finally disposed of.

The greatest care must, therefore, be bestowed upon fixing the gradients of sewers, it being always remembered that too steep a gradient is quite as undesirable as too flat a gradient. If it be too steep, the inner surface of the sewer is liable to corrosion, and, if too flat, a precipitation of solids, with consequent troubles and difficulties, ensues.

Every sewer, of whatever size or shape, has its own minimum self-cleansing gradient, and such gradient should be looked upon as an essential and on no account to be reduced even at the cost of additional lift.

Pumping.—Where a town is so circumstanced that the whole of its sewage would gravitate to one point but at too low a level to admit of a free discharge, the lifting of the sewage would best be effected by directly acting pumping engines. But gravitation to a single point is frequently an impossibility; and in such cases the town should be divided into sections, the sewage of each section, wherever necessary, being automatically lifted by one of the following methods, viz.,

(a) Air pressure, known as Shone's Hydro-Pneumatic System;
(b) Water pressure, known as the Hydraulic System;
(c) Vacuum, known as the Liernur Pneumatic System;
(d) Electricity, known as the Electrical System.

The most economical type of engine for pumping installations requiring not more than 25 brake horse power, is probably an oil or gas engine connected by gearing to a two or three throw vertical ram pump with externally packed plungers. If higher power be needed, steam is generally preferable on account of its great adaptability to a varying load. If an oil engine be selected, one of the

several types, which are adapted for burning the lowest grade of bulk kerosine oil, should be chosen, not only by reason of the greater economy of this oil, but also of its universal distribution amongst the marts and bazaars of the East.

For high or even moderate lifts, where the pumps have to be placed below ground level, there is a choice of the beam, the marine, or other types of vertical engine, of which the Worthington is a good example, coupled direct to the pump below, or of horizontal engines connected to the pumps through the medium of a bell crank placed in a frame above the pump well.

For low lifts, the Worthington direct-acting horizontal pumping engine or a centrifugal pump, coupled direct to a high speed horizontal vertical engine, is suitable; but the latter is not to be recommended for sewage pumping unless the total lift is less than 25 feet, for although its initial cost is cheap, its efficiency is low.

Vertical ram pumps are subject to less wear than horizontal pumps, as grit, which is always a special trouble in the East, does not lodge so readily on the moving parts of the former. Pumps of the bucket and plunger type are not as suitable as ram pumps for pumping sewage, on account of the excessive wear caused by grit between the bucket and the pump barrel. The valve area in a pump of this type is also necessarily very restricted—a very undesirable feature where sewage is to be pumped. With ram pumps the valves can be so arranged as to be entirely independent of the ram and can thus be made of sufficient area.

Now that an apparently unlimited supply of Petroleum Liquid Fuel is obtainable in both the Eastern and the Western Hemispheres, it will probably be rapidly adopted, in preference to coal, by Municipalities for use in Pumping Stations situated within and beside large cities. By its use the

nuisance of dust, smoke, soot, and ashes is, with ordinary care, entirely obviated—an important consideration to Municipalities, whose duty it is to set an example in such matters. Liquid Fuel is composed of a variety of substances, among which crude or semi-crude Petroleum or the residue of Petroleum after refinement chiefly figures. Its flash point ranges from 150° to 210° Fahrenheit, and its calorific value as compared with coal ranges from $1\frac{1}{2}$ to 1 to about 2 to 1. About $1\frac{1}{10}$ pint of oil is required per horse power per hour.

Pneumatic System.—Local circumstances often require the sewage from several sections of a City to be lifted or pumped, while the major portion of the sewage may have a natural outfall. In such cases, Shone's Hydro-Pneumatic Ejector System is very suitable. In this system the motive power is compressed air, carried in small pipes to various points and there utilized for the required purpose. The system can also be applied when the whole of a town's sewage has to be lifted, and the Patentees claim special advantages in this contingency ; but in such circumstances it would probably be more economical to adopt direct pumping, except in cases where the sewage has to be lifted at several points.

The following are the advantages claimed by the Patentees of this system and published by them:—

(1) The interception of the bulk of the sewage at higher levels and consequent saving of power as compared with a single pumping station in which the whole has to flow down to the lowest point, the continued fall to the pumping station being so much absolute waste power.

(2) The entire severance of each district from the main collecting sewers and the rest of the drainage area. Thus in the event of any epidemic disease break-

ing out in one district, it cannot be conveyed by sewers into healthy districts, as is often the case when the whole area is connected by a network of drains leading to a common outfall.

(3) The avoidance of deep cuttings and of large sewers, whereby great economy in initial cost is effected.

(4) The ready extension of the system in proportion as the population and occupied area increases, thus avoiding the immediate provision for probable future requirements and relieving the ratepayers of the present day of the heavy burden of providing prematurely for the wants of a possible future population.

The Patentees have failed to mention what, at any rate in the East, is such a very important advantage in connection with this system, and that is, the automatic working of the ejectors. Where skilled labour is rather the exception than the rule, this must be counted a distinct advantage. Once an ejector has been placed in working order, it requires little or no supervision, and its inspection once a day is usually sufficient. Cases have been known where ejectors have worked for months without having received any attention.

Fig. 1 illustrates a sectional view of a Shone's Ejector.

These ejectors consist of spherically ended cast or wrought iron containers, varying in capacity from 50 gallons upwards, and were, until quite recently, solely manufactured by Messrs. Hughes and Lancaster, of London, but owing to the expiry of the patent they are now obtainable from several makers. In Bombay they have been fixed in some districts in brick chambers as shown in Fig. 2, and in other districts in cast iron tubbings as shown in Plate 1. There are in this City several working with capacities varying from 100 up to 1,200 gallons each. The working of the ejectors is very simple. The sewage enters by gravitation through pipe A (Fig. 1), passes the flap G, and rises

in the container until the air within bell D is sufficiently compressed to lift the rod and cup B and open

SHONE'S PNEUMATIC EJECTOR.

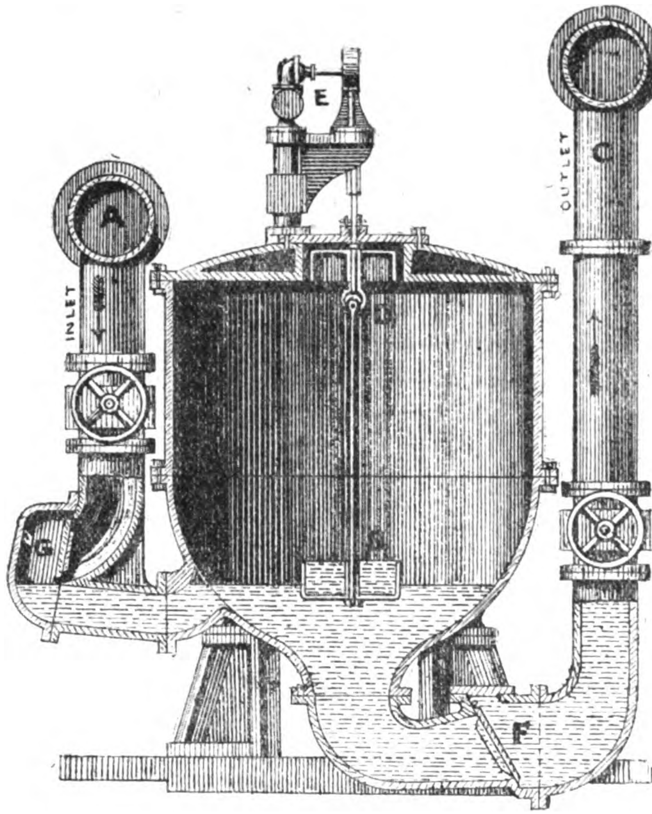
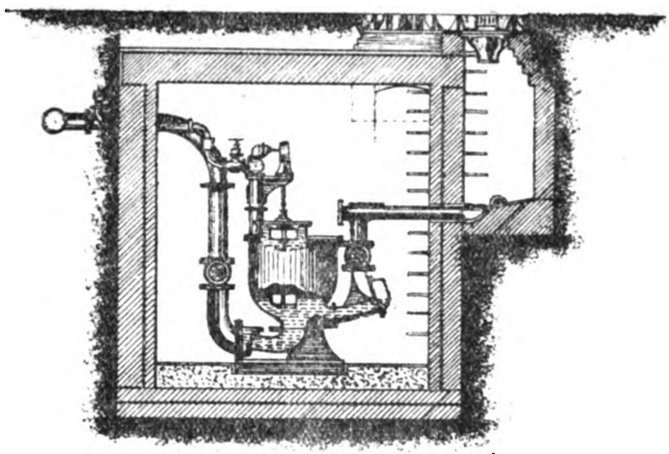


FIG. 1.

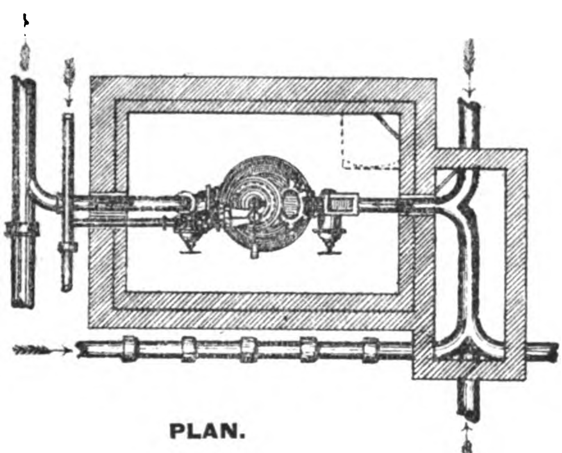
the valve E, which is connected with an air pressure main. As soon as the air is admitted from the pressure main, it is free to act on the surface of the sewage in the container. The pressure so applied closes the entry valve G and forces the sewage out of the container past the flap valve F into the pipe C and then into the sealed sewage main, through which it is forced to its outfall. The weight of

the sewage retained in the cup B is sufficient, when the sewage in the container falls below the bottom of the cup,

SHONE'S PNEUMATIC EJECTOR IN BRICK CHAMBER.



SECTION.



PLAN.

FIG. 2.

to close the pressure main valve E and to open an exhaust valve, through which the compressed air in the container escapes. As the air pressure is being exhausted, the height

of the sewage in the sealed main C closes the flap F, when the container begins to refill. This process is repeated automatically so long as any sewage flows out of the inlet sewer A.

The compressed air required for the working of this system having been generated at some convenient central station is conveyed to the ejector in iron or steel pipes, laid under the ground at a depth of some 3 feet, where they are free from all danger of breakage by traffic and steam rollers.

The advantages of a Shone's Ejector as given by the Patentees may be summed up as follows:—

(1) The working parts are reduced to a minimum and such as are requisite are not likely to get out of order.

(2) The parts with which sewage comes in contact contain no machine-tooled surfaces, which are unavoidable in pumps and get rapidly destroyed by the action of sewage, sludge and grit from the road detritus, etc. In the ejectors there is nothing but the hard skin of the original castings, coated with Dr. Angus Smith's composition, upon which the sewage can produce no detrimental effect.

(3) The friction of a pump piston and other working parts is avoided, the compressed air itself acting direct upon the fluid, without the intervention of any machinery, and forming an almost absolutely frictionless and perfect piston, past which there can be no slip or leakage.

(4) The cup-and-bell float arrangement is one that cannot possibly get out of order, as an ordinary rising and falling float would be likely to do.

(5) The only tooled parts are those in connection with the small automatic air valve ; this makes only

one movement of two or three inches for each discharge of the container of from 50 to 1,200 gallons (according to the size of the ejector), and is only in contact with the compressed air and out of reach of the sewage.

(6) The sewage inlet and outlet valves are so arranged as to give a free passage way of the full area of the pipe to all solids that the pipe itself can carry. No part of the container has any depression or traps wherein solid matter can collect.

(7) The outlet is from the bottom of the ejector so that the whole of the sewage, including solids, sludge, grit, and everything brought down the sewer, is discharged out of the ejector.

(8) For these reasons no screening or straining of the sewage is necessary, as is the case with pumps, and the great nuisance caused by the cleaning of pump gratings and sump wells is avoided.

(9) The sudden rush of the whole contents of the ejector, when the discharge is into a main gravitating sewer. forms a most effective flush.

(10) The ejector forms an absolute severance of the sewers of each district from the main sewer.

The size of an ejector required for any district is determined by the estimated quantity of the sewage of the district, its capacity being equal to the number of gallons of sewage per minute at the time of maximum flow, which, as is explained later, should be one and a half times the average per minute of the total daily flow. Each district should be provided with ejectors of the requisite size in duplicate, one being sufficient to cope with the ordinary work and the other held in reserve. The two ejectors should be worked alternately, say, every week or fortnight, to ensure that they are both kept in working order.

Cast iron pipes required for an air and sealed sewage mains need not be of the same thickness as those used for

water works, as the pressure under which they work is comparatively light. The following thicknesses are recommended for these mains:—

Diameter :	$2\frac{1}{2}''$	$3''$	$4''$	$5''$	$6''$	$7''$	$9''$	$10''$	$12''$	$14''$	$15''$
Thickness :	$\frac{3''}{8}$	$\frac{3''}{8}$	$\frac{3''}{8}$	$\frac{13''}{32}$	$\frac{7''}{16}$	$\frac{1''}{2}$	$\frac{9''}{16}$	$\frac{9''}{16}$	$\frac{5''}{8}$	$\frac{5''}{8}$	$\frac{11''}{16}$

The weights of pipes of these thicknesses, 9 feet long, exclusive of the socket, would be as follows:—

	cwts.	qrs.	lbs.
$2\frac{1}{2}''$ diameter	0	3	22
3" „	1	0	10
4" „	1	1	20
5" „	1	3	24
6" „	2	1	27
7" „	3	1	1
9" „	4	2	24
10" „	5	0	16
12" „	6	3	13
14" „	8	0	25
15" „	9	2	3

The air mains, after being laid and covered in, should stand a test of not less than $1\frac{1}{2}$ times the working pressure of air for two hours, with a loss not exceeding 20%.

They should be tested periodically, and when found to lose more than the above limit in *one* hour, steps should be taken to stop the excess leakage. To do this, each section should be tested separately, having previously examined all stop valves and arranged for the fixing of a pressure gauge to the main in each section.

After the section in which any excessive leakage has taken place has been located, the air should be blown off, and about 1 lb. of concentrated oil of peppermint, or other strong smelling volatile oil, should be introduced into the pipe by removing the stop valve cover at the end of the defective section nearest to the compressor station. On restoring the pressure, the air contained in the pipe will be heavily scented, and if the latter is not laid at a greater

depth than 3 feet, the position of the leak can generally be detected by carefully walking over the site of the pipe.

An early hour on a still morning should be chosen for the test, and it is scarcely necessary to state that the person conducting it should *not* himself place the essence in the pipe.

If this means of detection fail, the pipe will have to be cut in the centre of the section and each half tested separately, and so on in the same manner until the leak is confined to a comparatively short length, the whole of which can then be exposed. The leak will generally be found to be due to a cracked pipe, to a blown joint, or to a section of piping having settled in soft ground. Leakage in exposed joints which are only slightly defective can be ascertained by washing them over with soap and water, when the escaping air will blow small bubbles round the leak.

The following is a simple and practical rule for calculating the sizes of air and sealed sewage mains:—

It will be correct for all practical purposes to lay the sewage delivery pipes, so as to carry sewage at a velocity of $2\frac{1}{2}$ feet per second, and the air mains to carry compressed air at a velocity of 20 feet per second.

Divide the capacity of the ejector in gallons by twice the above velocities (in feet per second), and take the square root of the quotients. The results will give the diameter of the respective pipes in inches.

$$\left.\begin{array}{l} D = \text{Diameter in inches.} \\ G = \text{Capacity of the ejector in gallons.} \\ V = \text{Velocity in feet per second.} \end{array}\right\} D = \sqrt{\frac{G}{2V}}$$

The following example will illustrate the above rule:—

What should be the size of the ejectors, the air main, and the sealed sewage main for a district having a popula-

tion of 12,000, 6 cubic feet per head per diem being taken as the average water-supply?

Population of district = 12,000.

Average water-supply per day = 12,000 × 6 cubic feet or ×37:5 gallons = 450,000 gallons.

Gallons of sewage per minute = $\frac{450,000}{24 \times 60}$ = $312\frac{1}{2}$ gallons.

Quantity at time of maximum flow = $312\frac{1}{2} \times \frac{3}{2}$ = 469 gallons.

An ejector of 500 gallons capacity would therefore be required, and as one ejector should always be a stand-by, two ejectors of 500 gallons each should be provided. As regards the sizes of the mains, the diameter of the air mains would be equal to $\sqrt{\frac{500}{2 \times 30}}$ =4 inches (an even figure), and that of the sealed sewage main would be equal to $\sqrt{\frac{500}{2 \times 2 \cdot 5}}$ =10 inches.

The air pressure required to operate any particular ejector is calculated as follows:—

Suppose the level of the bottom of the ejector is 60 feet above any datum, and that of the end of the sealed sewage main, where the sewage is finally discharged, 90 feet above the same datum, the height through which the sewage is lifted would be 90—60=30 feet.

Suppose the sealed sewage main to be 10,000 feet in length from the ejector to the outfall, the diameter 12 inches, and the velocity $2\frac{1}{2}$ feet per second, the discharge would equal about 107 cubic feet per minute and (calculating from Taylor's Pipe Discharge Diagrams) the frictional resistance would amount to 2·8 feet per thousand, or a total of 28 feet for the whole length. Therefore, the total head to be overcome is equal to 30 feet the actual height and 28·0 feet the head due to friction, or 58·0 feet in all.

It requires an air pressure of 1 lb. per square inch to overcome a head of 2·3 feet of water, and therefore the pressure in the ejector to overcome the above resistance and drive out the sewage must be $\frac{58 \cdot 0}{2 \cdot 3}$ or 25·21 lbs. per square inch.

The diagram A, Vol. II. is taken from a paper read by Mr. Edwin Ault before the Society of Engineers and shows—

(a) the quantity of free air required per gallon of sewage for different lifts;

(b) the indicated horse power required per gallon of sewage for different lifts; and

(c) the percentage of usual effects obtained with Shone's Ejectors.

Plate 2 shews how the connections are made between an ejector and the sewers, and an ejector and the sealed sewage or rising main. There are two pipes rising from the top of the ejector, one of these being the air main, supplied direct from the engine house, and the other the exhaust pipe through which the compressed air, after having done its work by forcing the sewage through the outlet of the ejector, is allowed to escape. This exhaust air passes through a layer of coarse gravel before it finds its way out of the outlet shaft. This is an arrangement much advocated by the Patentees to dry the exhaust air before being finally discharged, and is not intended in any way to disinfect the air, for which some material, such as charcoal, would be necessary. The shaft nearest the ejector is the ventilator, into which the exhaust pipe discharges, each ejector chamber being supplied with a shaft of this description, generally about 50 feet high. This constitutes the only ventilation the Shone system has. The shaft shewn on the Plate furthest away from the ejector is an air inlet shaft, and one of these is usually placed at the head of each length of a gravitating pipe sewer. The object of this shaft is to supply fresh air to the pipe sewers,

replacing the foul air which is drawn out of them by the action of the exhaust air from the ejector. The sliding openings in the heads of these shafts require to be carefully adjusted, those nearest the ejector chamber being partially opened, those further away being fully opened so as to obtain a regular distribution of fresh air.

The ventilating shafts work very efficiently on this system, the exhaust air discharged through a nozzle into the shaft inducing a current and thus drawing a quantity of foul air from the gravitating sewers ; but this foul sewer air is very apt to be discharged from the ventilating shafts in puffs and carried by the prevailing wind, long distances, into neighbouring houses. This has been the experience in Bombay, and a serious nuisance has at times resulted. There are many reasons which prevent ventilating shafts being raised to any great height, and in the neighbourhood of dwellings it is consequently desirable to treat the gas in some way before it leaves the shaft.

The main air compressor station at Love Grove, Bombay, contains four horizontal triple expansion condensing engines. Each engine has three air compressing cylinders, the pistons of which are coupled direct to the steam pistons. Two of the engines indicate 220 horse power each on a full load, and are each capable of compressing 2,466 cubic feet of free air per minute to a pressure of 23lbs. above the atmosphere. The other two engines are each half the size of the above.

The first cost of the two smaller engines was greater than that of one of the larger size, but in a large installation of this kind, where the day and night loads vary considerably, it is always advisable to have two sizes of engines in order to avoid the loss which would be occasioned by working a large engine much below its maximum speed.

The two larger-sized engines, or one of the larger and the two smaller-sized engines when working together, are capable of lifting 14,000 gallons of sewage per minute to heights varying from 17 feet to 44 feet dynamic head.

Steam is supplied from three Babcock and Wilcox water tube boilers, each having 1,426 square feet of heating surface and capable of working up to a pressure of 200 lbs. per square inch.

A Green's Fuel Economiser of 168 tubes is fixed in the main flue from the boilers for the purpose of heating the boiler feed water.

From a purely sanitary point of view, the Shone system is *theoretically* perfect, for the sewage is rapidly removed in a fresh state from the inhabited portions of the town to the ejectors, but this undeniable advantage is accompanied by certain drawbacks: it is expensive both as regards efficiency and initial cost, the apparatus required including the air compressing machinery, the cast iron air mains and sealed sewage mains, and its ejectors and ejector chambers; these, however, are not luxuries but necessities where a gravitation system cannot be adopted and sanitary conditions are desired. The defects of the system and loss of efficiency are due to—

(1) the impossibility of using the air expansively as in steam;
(2) the heating of the air during compression;
(3) subsequent loss of pressure on cooling;
(4) the leakage of air mains;
(5) leakage of the valves at the ejectors; and
(6) the difference in head at the different ejector stations.

The efficiency obtained varies with the head to which the sewage has to be lifted, as shown by the diagram referred to above.

Many have raised valid objections to the Shone system on the score of its low efficiency. Mr. J. Forrest Brunton, M. Inst. C.E., the Municipal Engineer of Karachi,

recently wrote an article entitled "Notes on the working of the Shone System of Sewerage at Karachi" for the Institution of Civil Engineers, in which he shewed that the efficiency at Karachi was 0·263. This is somewhat higher than the efficiency at Colaba, in Bombay, where a few years ago it was found to be 0·223. But, serious as these objections are, one must not lose sight of the commercial aspect of the working of the Shone System; for loss of efficiency is largely counterbalanced by the fact that skilled supervision is not essential, by the non-screening of the sewage and by the automatic working of the ejectors.

The Shone System, which has been introduced into several districts of the City of Bombay, has so far proved very successful. The first installation was put down in the Colaba District in 1895-96, and provides for a present population of 18,000 people and for a prospective population of 28,000. In 1900-1901, a further extension was made for the district of Mazagon, which houses a population of 33,000. In 1901-1902, the system was further extended to the Parel and Chinchpokli districts, having a population of 85,000. Further details of these installations will be found in Chapter VIII.

In the immediate neighbourhood of some ejector stations in Bombay, the Author has noticed, during the time of the maximum flow of sewage in the sewers, that foul air is apt to to be forced out of the manhole covers at road level with a resulting nuisance. This arises from the fact that during the period of discharge by the ejector, the inlet valve is closed and the sewer has consequently no outlet, with the result that the sewage agglomerates in the sewer, rises in the manholes, and by compressing the air in the shafts forces it through the covers.

A remedy for this with existing ejector stations is the provision of high ventilating shafts above the houses to relieve the pressure, coupled with air-tight manhole covers.

In designing new ejector stations, it is desirable, after all calculations for levels have been fixed, to lower the Station together with the inlet manhole by an amount sufficient to give in the inlet manhole a storage capacity equal to the size of the particular ejector.

Rangoon was the first city in the East to adopt the pneumatic system for the lifting of its sewage and now has about 26 ejector stations at work, each ejector having a capacity of 200 gallons. These ejectors are fixed in duplicate and, on account of the sandy and water-logged nature of the soil, are placed in cast iron tubbings as shewn on Plate 1.

Mistakes were doubtless made and many defects encountered in the early working of the system in that City, but most of these have now been rectified and the system seems to be very efficient.

The great mistake made in the Rangoon installation was undoubtedly that of laying sewers of too small a diameter. These sewers, which are of cast iron, measure only 6 inches in diameter and have always caused considerable trouble by continually getting choked, to the extent of an average of 3 chokes per day. This trouble cannot now be rectified without replacing the sewers by others of larger diameter.

Amongst the defects encountered were (a) the non-provision of a sluice valve outside the ejector chamber on the discharge pipe in order that the ejector chamber might, when required, be cut off from the sealed sewage main; (b) the non-provision of inspection chambers or manholes on sealed sewage mains, leading to much trouble when a choke occurred; and (c) the discharge of the air exhaust into the ejector chamber instead of being taken up by means of a pipe into the open air. On one occasion this resulted in a serious explosion, causing considerable damage to the chamber. Also, the inlet valve falling on its seat

with a shock caused excessive vibration to the ejector. This has now been overcome by facing such valves with rubber or some similar material. No reducing valves were provided on the air mains in order that the pressure delivered in the ejectors might be regulated in proportion to the resistance to be overcome.

The total cost of the sewerage of Rangoon on the Shone System amounted to Rs. 2,352,733, which works out to Rs. 19 per head of population or in sterling about £ 1-6-0. A more detailed account of the sewerage of Rangoon is given in Chapter XI., kindly furnished to the Author by Mr. Edwin Ault, who designed not only the original drainage but the proposed extensions and alterations.

Karachi has also been drained on the Shone System and a separate account of this is given in Chapter X.

Hydraulic System.—As an example of the use of hydraulic power for lifting sewage from low-lying areas, which cannot be drained to a general outfall by simple gravitation, may be mentioned the Installation at Woking, in Surrey, which was completed in the year 1900. As in the Shone Hydro-Pneumatic System, the power is generated at a central station and transmitted through pipes to the various automatic pumping stations which, in the town under reference, are four in number. Several reasons induced the Engineers, Messrs. John Taylor Sons and Santo Crimp, to adopt water power in preference to air in this district. The principal reason was the desirability of placing the central station on the sewage farm where the whole of the sewage was purified. The power water being obtained from the subsoil water on the farm, an excellent means of assisting to keep the subsoil water at as low a level as possible was thereby provided. A well was sunk on the farm near the engine house, from which all the water necessary for working the pumps was obtained. The natural level of the water in the well was, on the

average, some 6 feet below ground level, and is now, no doubt, being maintained in level by the sewage placed upon the sewage farm. As, however, the effluent coming from the farm is an extremely good one, the water in the well maintains a fair degree of purity.

Another reason for adopting hydraulic power was that the arrangement provided a means of storing the water in overhead cast iron tanks after it had done its work of pumping the sewage, and subsequently employing it for street watering or sewer flushing. This arrangement at Woking is, as far as the Author is aware, quite a new departure, and has not been utilized elsewhere.

The hydraulic pressure employed is 200 lbs. to the square inch: this is rather a low pressure to adopt for power transmission, but, as has already been explained, there is in this case plenty of water, and in fact the more used the better. The adoption of a low pressure enabled the pipes required for conveying the power from the generating station to the automatic pumps to be of a lighter and less expensive make than they would have been had the pressure been 1,000 or 1,200 lbs. to the square inch, and reduced the cost of laying and jointing.

An additional and very important advantage in the adoption of the low pressure is that the size of the accumulator ram can be increased, thus preventing sudden and rapid oscillations when the outlying sewage pumps are automatically opened or closed.

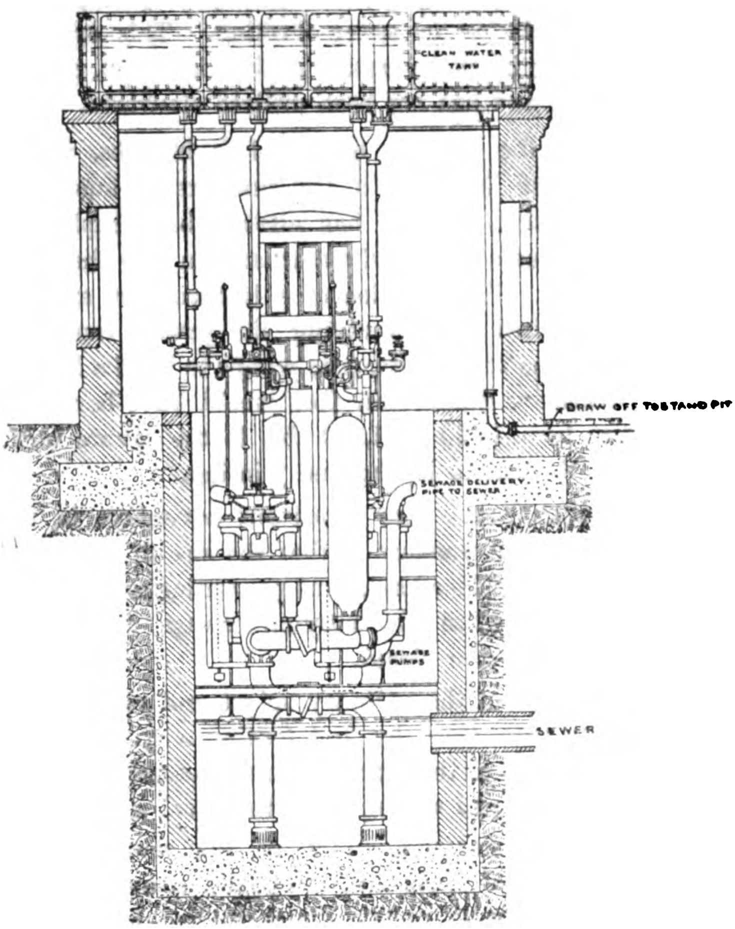
The pipes are of the ordinary spigot and socket type, and the joints were made by first forcing a strip of cold lead into the bottom of the socket and subsequently running the joint with lead and setting up in the usual manner.

The power generating plant at the sewage farm consists of a pair of horizontal compound steam engines, each driving hydraulic pumps direct in line behind the cylinders. These engines work at a steam pressure of 140

lbs. per square inch, and make 90 revolutions per minute. The diameters of the high and low pressure cylinders are 6 inches and 10 inches, respectively, both having a stroke of 12 inches. The pumps, which have 4½-inch pistons and 3-inch rams, discharge direct to an accumulator, and from thence the water is forced through the hydraulic main to

AUTOMATIC HYDRAULIC PUMPING STATION.

FIG. 3.



Scale, ¼ inch = 1 foot.

the automatic pumps at the various outstations. The accumulator ram is 11 inches diameter with a stroke of 10 feet. The rise and fall of the accumulator by means of an equilibrium valve on the main steam pipe, which is connected to a weight suspended directly over the accumulator, automatically admits steam to, or cuts it off from, the engines. It is thus only necessary to keep up the pressure of steam in the boilers for the whole system to be in actual automatic working order. The machinery at the various automatic lifting stations, which is shewn in detail in Fig. 3, is in duplicate, and is controlled by means of counterbalanced floats which start or stop the pumps according to the level of the sewage in the sumps. The pumps are single acting, the plungers being forced downwards by means of a fixed operating ram, within which slides an operating cylinder. A slide valve worked by hydraulic pressure is alternately placed in communication with the pressure water and with the exhaust. The upward stroke is accomplished by means of two side rams constantly open to the pressure. The plungers of these pumps vary in size at the various stations according to the quantity of sewage to be disposed of, the largest being 2 feet in diameter with a three-foot stroke, the smallest being 1 foot diameter with the same length of stroke. The average lift is 16 feet. The installation, with the exception of the pressure and rising mains, was laid down by the Hydraulic Engineering Company, Chester, and so far the results have borne out the most sanguine hopes of the Engineers.

Margate is another instance where sewage is lifted by hydraulic power, the automatic pumps used being those known as the Latham Davey Hydraulic Pumps. In this case special allowance had to be made for the fluctuating population which, though normally amounting to 20,000, increases to more than three times that number in summer.

The drainage is on the "separate" system, pumping being only used when gravitation fails. The sewage, after

being raised by the hydraulic pumps, is discharged into a high level sewer. The high pressure water for these pumps is obtained by means of a pair of Worthington direct-acting high pressure engines. The full hydraulic pressure is 700 lbs. per square inch. The accumulator cylinder contains a 4-inch ram weighted to 6 tons. There are three pumping stations at different points, the lifts being 19, 28, and 38 feet, respectively. Each pump can work twelve strokes per minute, delivering 40 gallons per stroke.

Vacuum System.—The Liernur "Improved" Pneumatic Sewerage System is one which has been introduced in several towns on the Continent, and the Syndicate working the patent have constructed at their own expense an installation at Stanstead in England.

By this system all the sewage is conveyed through iron pipes to a hermetically closed sewage collecting chamber, by the creation of a partial vacuum in the latter. The term used by the Syndicate for this arrangement to convey the drainage of the district is "Pneumatic Sewer Net." This "sewer net," or system of pipes, does not in any way deal with the surface water or sullage, but is meant to receive and convey only the fœcal matter and household slops, which are collected, after passing down the soil pipes, in a small cast iron siphon tank, hermetically closed and placed below them.

From each siphon tank there is a cast iron branch pipe which joins a cast iron street sewer placed in the road. The town to be sewered is divided into a number of districts, each with a population of about 3,000. In the centre of each district there is a cast iron underground reservoir, which is called a "district reservoir," and to which all the cast iron street sewers are connected.

Every day, by the operation of valves, these "district reservoirs" are put in communication with the street

sewers, and under the pressure of the external air, the fœcal matter in the house tank siphons is carried to the "district reservoirs" and thence on to the collectors, and finally to a central reservoir placed at the Pumping Station.

LIERNUR'S SYSTEM.

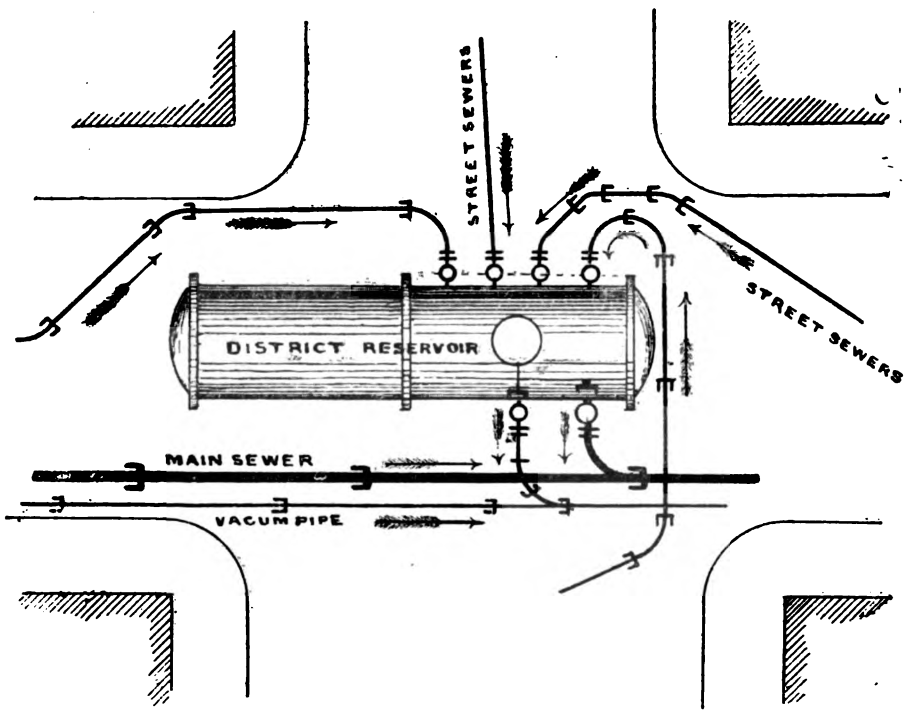


FIG. 4.

The "district reservoirs" are joined by a series of pipes called main collectors and the main collectors are linked to the central reservoir at the pumping station, situated preferably outside the town, which contains the necessary pumps to create a vacuum in the whole of the system. It follows that an indispensable condition for the

proper working of the system is the absolutely air-tight condition of the whole of the "sewer network," the motive power being atmospheric pressure. There is said to be no communication with the external air except through the soil pipes, which are supposed to act only as air inlets; but considering that each house is only put in connection with the vacuum for a few minutes each day, it is clear that the soil pipes must act as air outlets for the major part of the 24 hours. An advantage claimed in this system is that pipes may follow the contour of the ground, no fall being necessary. Fig. 4 shews the general arrangement of a "district reservoir." The sewage of the whole town is said to be thus driven in a few hours—the working of each "district reservoir" requiring only from 12 to 15 minutes—into the central reservoir at the pumping station, at which place it can be either dealt with biologically or the liquid evaporated and finally dried as Poudrette.

In September, 1903, the Author visited Stanstead in order to see the Liernur System at work.

Stanstead is a small town in Essex and the system has been installed there for two years, but it is only recently that the Local Government Board finally passed the system as satisfactory and allowed it to be taken over by the local authorities.

It is calculated that 10 gallons of sewage per head per day find its way into the Liernur system pipes, and this sewage after journeying to the storage tanks alongside the Pumping Station is pumped into a gravitating sewer which discharges on to a Sewage Farm in the higher part of the Town. One mile of 4-inch and 5-inch cast iron pipe sewers has been laid in connection with the system. Each house is connected to the sewers by means of an air-tight cast iron housefall or siphon box, which acts also as an inspection chamber and, when full, holds about 20 gallons. All siphon boxes are connected to 4-inch branch

pipes and all branch pipes to a junction reservoir, 6 feet by 3 feet by 3 feet, joined to a 5-inch cast iron main pipe, which is directly connected with the vacuum reservoir.

To actuate the system, a vacuum pump is worked until the gauge of the vacuum reservoir registers 15 inches. Having obtained a sufficient vacuum in the vacuum reservoir, further arrangements are simple. A tap is opened at a junction of the 4-inch and 5-inch cast iron pipes and all the contents of the siphon box on that branch pipe are drawn into the junction reservoir and from there to the 5-inch pipe, which carries them to the vacuum reservoir at the Pumping Station. This takes but a short time, for, the velocity of the sewage in the pipes is said to equal 10 feet per second. This having been done at all the junctions, the vacuum is shut off, and the contents of the reservoir are allowed to flow by gravitation into an underground storage tank, from which they are pumped to the sewage farm. The whole operation lasts about 30 minutes.

There are no ventilating shafts at Stanstead and the foul air drawn through the pipes is dissipated through a shaft at the pumping station.

The installation has cost £2 per head of population, but is reputed to be adequate to deal with three times the present population.

All the sewage from water closets and kitchens is disposed of in the system.

The pumping station is situated at the lowest part of the town and consists of the following machinery: one 8 horse power gas engine; one $\frac{3}{4}$ horse power vacuum pump; one vacuum reservoir, having a capacity of 3,000 gallons; and one pump for lifting sewage to the high level sewer from the storage tank.

In October, 1903, the Author visited Trouville-sur-Mer to inspect the Liernur System there. Trouville lies at the

mouth of the river Seine. Its normal population is 7,000, but during the three months of the summer season it increases to between 30,000 and 40,000.

Of the 1,800 houses in Trouville about 900 have been connected to the sewerage system.

The cost of the whole work has amounted to £12,000, including sewers, siphon boxes, reservoirs, outfall works, and engines, and the annual working expenses are reported to amount to only £200.

This system is on a larger scale than Stanstead, and the Pumping Station contains machinery for working a 30 horse power vacuum pump. Alongside the engines are two steel cylinders, each 10 meters (32′ 10″) long by 2 meters (6′ 7″) diameter. These cylinders are placed one over the other, the lower being below the level of the engine room floor and the second above it. The upper cylinder is the exhaust and the lower, which is connected with it, receives the sewage. Connected with the sewage cylinder is an 8-inch centrifugal pump for raising the sewage into a covered reservoir outside the engine house: the reservoir has a capacity of 3,300 gallons. After settling, the sewage is allowed to flow off by gravitation into the adjoining river.

Trouville is divided into nine sewerage districts and at the lowest point of each district is placed a district reservoir. Each of these reservoirs is in communication with the pumping station by means of a 4-inch cast iron vacuum pipe and also by means of an 8-inch or 10-inch cast iron collecting sewer. These pipes run parallel to each other in the street. The house branches are all 4 inches in diameter. The siphon boxes are of the same pattern as those at Stanstead and hold about 20 gallons when full. To work the system, the vacuum at the pumping station is raised in the exhaust chamber to 16 inches, and the sewage then flows in from the collecting sewers and fills the sewage

cylinder. A cock is now opened at each district reservoir, placing all the siphon boxes and branch pipes under vacuum, which causes the sewage from every siphon box to rush in with great velocity. This procedure takes place at all the district reservoirs, the sewage passing in each case from the siphon box into the collecting sewer and from the collecting sewer into the sewage cylinder at the pumping station. The velocity in the collecting sewers is said to be equal to 6 feet per second. The district reservoirs are emptied as often as necessity requires.

One of the objects of the Author in visiting Trouville was to experiment with the system and ascertain whether solid matter could be drawn without difficulty through the pipes; for the Corporation of Bombay were desirous of knowing whether the system could be utilized in Bombay for the removal of fœces which is now removed for the most part by hand carriage.

The Trouville authorities, at the request of Mr. Liernur, were good enough to lay down a length of 4-inch pipe in the compound of the pumping station for this experiment. The 4-inch pipe was laid at almost a dead level but not in a straight line and was 300 feet in length. Three inlets were provided to represent siphon boxes. At one end a retaining box, 24 inches by 20 inches by 12 inches, being in reality a housefall box in ordinary use in Trouville, was placed with a grating across it to prevent the solid matter passing out of the box. The retaining box was made air-tight and connected to the 4-inch vacuum pipe used in connection with the Trouville sewerage system. The following materials were mixed together:—18 ½-inch road metal cubes, 36 sticks, 4 to 5 inches long, 24 pieces of cloth, 24 lbs. of grass and stable litter. These were moistened with water, mixed, and the whole placed in the inlet branches of the pipe, which were then rendered as air-tight as possible.

At the further end of the 4-inch pipe two automatic flushing tanks, one holding 16 gallons and the other 24 gallons, were placed. These tanks automatically emptied themselves each time the vacuum was applied. A gauge was placed at the receiving tank to register the vacuum in the 4-inch pipe. The highest amount registered on that gauge was 4 inches. This small result was probably due to the fact that the pipes and the inlets were not completely air-tight. On the suction being applied for about 5 minutes the receiving box was found to contain 7 pieces of road metal, 20 rags, 26 pieces of stick, all mixed with grass and stable litter. On the vacuum being again applied most of the remaining material passed out. This was considered very successful and proved that the system was capable of drawing through pipes any ordinary solid matter likely to be met with in sewage. The velocity of the metal brought forward in the pipe was very great and must have been at one time nearly 10 feet per second.

Trouville is a much better example of the Liernur System than Stanstead. It is on a larger scale and has been worked with considerable success for a number of years, and the authorities are loud in praise of it. The Author was favourably impressed with the simple and efficient manner in which the sewage was removed. The cost of the construction and the annual charges for maintenance as given are exceedingly small for a sectional system of sewerage.

Electrical System.—The adoption of electricity as a motive power for lifting sewage is of comparatively recent date, and only a few such installations are as yet at work.

In towns, which have electric tramways and electric light and possess any surplus power, it might be both desirable and economical to make use of this power for lifting sewage, if such lifting be necessary.

Electricity can, as is well known, be transmitted great distances at little cost beyond the initial outlay upon the cables, so that in other places where sufficient water power can be obtained all the year round at a convenient distance from the point where the sewage is to be lifted, it may be economical to install turbines and electric generators at the source of power and electric motors coupled to pumps at the pumping station.

One of the earliest electric sewage pumping installations was laid down at Coombs, near Stowmarket in Suffolk, England, by Messrs. John Taylor Sons and Santo Crimp.

The drainage of Coombs, which is only a small village, was undertaken in conjunction with that of Stowmarket and Stow Upland, the sewage from both places being disposed of on a sewage farm. This farm being on a higher level than the village of Coombs, it became necessary to provide a small pumping installation for lifting purposes, which would entail the minimum amount of annual expenditure for upkeep and attendance.

An electric installation having been provided at Stowmarket for the lighting of that town, it was decided that no better arrangement could be adopted than to utilise the surplus power there generated. The following is a brief description of the arrangement of pumps and motors:—

> The machinery is in duplicate, each set comprising a 3-throw pump driven by an elector motor through worm gearing running on ball bearings. The bearings of the motor are lubricated automatically, the worm and wheel running in an oil bath, so that no attention should be required other than to start the motors and stop them, when necessary. But even this labour has been dispensed with by the use of automatic switches, operated by floats controlled by the level of the sewage in the sump adjoining the pumping station. These switches can be adjusted so

as to start either pump in advance of the other, and a convenient arrangement is to allow one pump to deal with the ordinary flow of sewage, the second pump remaining in reserve and only starting in the event of the first being unable to cope with any increased flow of sewage. As either pump can be made to start first, they can be worked alternately week by week, or month by month, as desired, so that both sets of machinery are kept in good working order and do an equal amount of work. In a pumping installation, which derives its power from an electric light plant, the current must be so drawn off as to cause no great fluctuation likely to appreciably affect the electric lights burning on the circuit; and for this purpose on the Coombs installation an arrangement consisting of a dash-pot with a multiple contact automatic switch has been used, by which the starting current is gradually turned on, the movement occupying a period of from 5 to 10 seconds.

The absence of steam, gas, or oil engines in a pumping installation of this description enables the station to be kept scrupulously clean. The plant has now been working for nearly two years and has given considerable satisfaction.

The same firm has recently, at Shrewsbury, erected in St. Mary's Water Tower an automatic electrically driven pumping machinery. The electric motors are 7 H.P. and are coupled direct to two sets of 3-throw pumps with 6¼-inch diameter plungers and 9-inch stroke. They are driven from the Corporation current through electric motors and worm gearing. After a careful test, extending over several weeks, it was ascertained that with 2,654,200 gallons of water lifted to an average height of 75 feet, by 1,803 units of electricity, the efficiency was 41·82 per cent. This probably represents a fair efficiency for electric pumping. With a smaller lift it is probable that the efficiency would be slightly higher. It may be confidently asserted that the

efficiency of an electrically driven pump will vary between 40 and 50 per cent.

At Cardiff also, an electrical plant for pumping the sewage has been erected by the City Engineer, Mr. W. Harper, the power being drawn, as at Coombs, from an Electric Light Installation.

The motors and pumps are placed in a small chamber beneath the roadway, and the motors are directly connected with 3-inch centrifugal pumps with vertical spindles: special bearings are fitted to the motors, so that the spindles run in a bath of oil and the thrust is taken by adjustable ball bearings.

The speed of the motors is about 1,300 revolutions per minute, and they are series wound and work on a 500-volt circuit.

The installation has given great satisfaction, and is economical and clean in working.

In Bedford, a town of considerable proportions, the Corporation some years ago made use of their surplus electric power to pump a portion of their sewage. 25 H.P. electric motors in duplicate were provided for driving a 7-inch centrifugal pump, also in duplicate. The electricity is generated at works situated about a mile from the sewage pumping station. The cost per unit was reduced until it arrived at three half-pence. But even at this rate the cost was calculated to exceed by £400 per annum the cost of a steam-driven system. Moreover, no economy in staff was possible, the same number of men being required as when steam was used. The Corporation therefore decided to abandon electric motors and revert to steam driven pumps.

In selecting for any particular town any one of the systems described in this chapter, it must be remembered that financial considerations, though very important in a sewerage scheme, should take only a second place, the first

desideratum being the efficient removal of the sewage. Of the various systems above described, the simplest and the least expensive is undoubtedly the "gravitation" system. Here the sewage flows to the outfall through conduits laid at gradients, which should be self-cleansing. This is the ideal system which every Sanitary Engineer desires to obtain, but unfortunately in most towns of any size it is impossible and some kind of pumping has to be resorted to.

It is not necessary in all cases to have recourse to sectional pumping. In many schemes the sewage of a town can be gravitated to a single point and there lifted in one lift. This is often the most economical system next to that of simple gravitation.

In dealing with the various systems of sectional pumping, it is very difficult to say that either one or the other stands first in any marked degree. Circumstances vary so much in many places, and where in one position the Shone Hydro-Pneumatic System of drainage may be the most economical, a hydraulic system may be the most expensive, and *vice versâ*. Generally speaking, there is no doubt that the first cost of Shone's Hydro-Pneumatic System, as well as the expense of working it, is cheaper than that of any hydraulic system. Lighter and smaller pipes and much less pressure are needed to work this system. The cost of water is greater than that of air, and although the water used in the hydraulic system is also used to flush the sewers, it takes up space in them, and allowance must be made for it. The Author has had considerable experience of the Shone System of Drainage and, excepting the few disadvantages mentioned earlier, it has always given satisfaction.

Since the paragraph on page 37 of *Oriental Drainage* was written regarding the Liernur System, the Author, as mentioned on pages 26 to 30, has had the advantage of seeing it at work in two places, *viz.*, Stanstead and

Trouville, and has modified his opinion of it so greatly that he has recommended the Corporation of Bombay to erect a small installation in the City for the removal of the night-soil of a small district to a central depot, where it can be discharged by gravitation into a main sewer. The necessity for hand-carriage will thus be obviated.

Experiment, as above stated, has proved that the belief, that the Liernur System does not deal with all matters which usually find their way into a sewerage system, is erroneous.

The system has been installed in eleven towns and cities on the Continent and in the British Isles, and many other installations are under consideration. The largest installation is that of Amsterdam, where 200,000 people are served.

As regards the cost, so far as figures have been seen by the Author, they compare very favourably with those of any other sectional system: and he has good grounds for holding that the system can be applied with special advantage to towns and cities in the East, where the water supply is so limited as to be hardly sufficient for an ordinary water carriage system.

CHAPTER II.

SEWERS AND THEIR CONSTRUCTION.

The materials other than metals, such as iron and steel, used in the construction of sewerage works are cement, lime, sand, mortar, concrete, bricks, stone, and pipes.

Cement.—The best known natural cement is Roman cement, which is made from a stone found in the form of nodules in the Island of Sheppey and elsewhere in the geological formation, known as "London Clay." This cement was first discovered by a Mr. Parker in the year 1796, and usually contains 55 parts of lime, 38 of clay, and 7 of iron. In Russia, America, India, and elsewhere, similar natural cements have been met with, but they are comparatively rare. This rarity necessitated the making of an artificial cement and we are much indebted to General Paisley for one of our best and earliest artificial cements: it was he who first proved that an artificial cement equal to that obtained from natural sources could be prepared; and he composed it of a mixture of chalk and blue alluvial clay, the proportion being four parts by weight of chalk and 5·5 parts of clay.

The principal cement used in sanitary works is that known as Portland cement. Portland cement is so named simply because of its similarity in colour to Portland stone. but it has no connection with it in any other way. It is usually manufactured on the banks of the Thames and

the Medway, from a mixture of chalk and mud obtained from the beds of those rivers. Other materials are also employed in its manufacture, such as blue lias limestone and shale. There are many makers and many brands of this class of cement, but in all a mixture of clay and lime after calcination—in the proportion of not less than 35 per cent. of clay and not more than 61 per cent. of lime—is necessary. If there be too large a percentage of clay, the cement is very quick-setting, and never attains the strength of a more slow-setting composition. A slight excess of lime enables the materials to burn at a high temperature, thus making a slow-setting and strong cement. In all cements, fineness is a great feature, and a good cement should pass 90 per cent. of its bulk through a sieve containing 5,800 meshes per square inch.

The composition of a thoroughly good Portland cement is:—

	Per cent.
Alumina and Oxide of Iron	12
Silica	23
Lime	61
Magnesia	1
Sulphuric Acid	1·5
Carbonic Acid and moisture	1·5

Portland cement should always be tested before it is used, for considerable variations will be met with even in the best brand. For sewerage works, only the best quality should be used. The most important test for cement is that of tensile strength; and for this test small quantities should be taken from a number of casks. The samples should then be made into briquettes, one square inch in section at the centre, and immersed in water after seven hours, care being taken that there be no disturbance of the water after the briquettes are immersed. The briquettes should remain in water for periods varying from 7 to 30 days.

Those immersed for seven days should stand without fracture a tensile strain of at least 350lbs. per square inch; those immersed for fourteen days at least 450lbs. per square inch; while those immersed for a month not less than 580 lbs. per square inch.

Another test is the sand test. Briquettes made in the proportion of three parts of absolutely clean sharp sand and one of cement should be left standing one day in the mould and twenty-seven days in water; they should then bear not less than 200lbs. of tensile strain per square inch; any less strain would betoken a doubtful cement. Many Engineers prefer this test to the former one, as pure cement is not extensively used.

Rapidity of setting may be judged by the use of a machine known as Vicat's Needle. A pad of cement should not be so set in less than one hour that the needle cannot penetrate it.

The specific gravity of Portland cement, one month after manufacture, should not be less than 3·05.

Before being used, cement should, as a rule, be cooled by spreading it on the floor of a dry room. This also allows the free lime which exists in all new cement to slake; if this is not done, there is a likelihood of its "blowing" after the work has set.

Only just so much of the cement as is required for immediate use should be mixed at one time, as once it has commenced to harden it cannot be worked up again. The amount of water necessary in mixing cement varies with different makes, but it should usually be 20 per cent. of the volume of dry material.

Portland cement is the only cement that should be used for works that sewage may come in contact with, as it is practically unaffected by acids, should such exist in the sewage. Cement, said to be similar to Portland

cement, is now being made in Madras and Calcutta, but the Author has had no experience of it and can therefore say nothing as to its quality.

Sand.—The sand used should be sharp and clean and entirely free from loam or any organic matter. The kind principally used in Bombay is basaltic sand, washed during the monsoon months from neighbouring hills of volcanic formation. The use of sea-sand is undesirable with lime—at any rate, until thoroughly washed in fresh water—because of its liability to sweat in a humid atmosphere, but with cement slight salinity makes no difference.

Lime.—Lime may be divided into two classes:—

(1) (*a*) Fat or common lime, which gains no consistency under water, being only pure chalk without any adulterants.

(*b*) Non-hydraulic lime, which is a combination ot lime and non-soluble mineral matter, such as silica and alumina.

(2) Hydraulic lime, which is obtained from limestones having a greater or less percentage of soluble silica and alumina.

Fat lime is a rich lime, is found in India, principally in Madras, and contains an excessive quantity of carbonate of lime. It can be usefully employed in whitewashing. plastering, and stucco work, as it takes a good polish.

Non-hydraulic lime is a lime deficient in soluble silica and alumina and requires the addition of pumice to give it hydraulic properties. Most of the pumice used in India is obtained from Aden and is a volcanic product.

Probably the best known hydraulic lime in India is found in the form of kankar. Kankar is obtained either in nodules on or near the surface of the ground or is dug up in large lumps from pits in alluvial soil. Kankar is

a species of subsoil tufa, formed by the deposition of calcareous matter extracted from beds of sand and clay in minute quantities and re-deposited in the form of kankar. A good kankar should give the following proportions:—

Carbonate of lime	112 grs.
Clay	9 „
Sand	29 „
Total	150 grs.

An easy test for determining the quality of kankar is to pound 150 grains, so that it will pass through a fine sieve. Add sufficient hydrochloric acid until effervescence ceases and filter carefully through blotting paper. That which remains is clay or sand, or both. The difference between this weight and the 150 grains represents the carbonate of lime dissolved by the hydrochloric acid. The remainder should be now washed by decantation so as to get rid of the lighter particles of clay until the sand is left, which should be dried and weighed. The difference gives the proportion of clay and sand.

In purchasing lime, it should be remembered that the addition of 10 per cent. of water will give a 30 per cent. increase in measurement—a fact which should not be overlooked in taking over lime for works.

Mortar.—The proportions of sand and cement are usually from two or three of sand to one of cement, measured dry. Cement mortar for jointing pipes should be in the proportion of one part of cement to one part of sand. Such cement and sand should be mixed dry before water is added, and care should be taken that water in excess is not used. Sand should be screened and only the finer portion used in cement mortar. Cement mortar should never be ground.

In lime mortar, the best proportion for Indian lime of good quality is two parts (by measure, dry) of lime and three of sand. For hydraulic works and foundations, equal parts of lime and sand should be used; and in the case of lime being non-hydraulic, the mixture for mortar should be one part lime, one part surki, and one part sand (surki being bricks pounded very finely). As a rule. kankar should not have surki mixed with it: such a mixture gives a weakened mortar. It is not easy to lay down a hard and fast line for the properties of lime mortar: every Engineer should make experiments for himself with the lime of his district. The ingredients for mortar should be well mixed, the lime being previously screened to remove extraneous unburnt matter, and then wetted and ground in a mill, ghanni, or mixing machine; in the case of a single ghanni being used, it should usually be subjected to at least 160 full rounds of the ghanni stone, or as many rounds as experience may show to be necessary. A ghanni is a simple form of mill and consists of a circular channel, usually 30 feet in diameter, 1 foot 4 inches wide, and about 1 foot deep, lined at the bottom and sides with flag stones set dry. In the centre is a short vertical post, round which revolves a horizontal bar, to the outer end of which a bullock is yoked. A grinding stone, some 2 feet 6 inches in diameter and 1 foot in thickness, is attached to the bar and is worked round in the channel by the bullock. A ghanni may have two grinding stones attached to two horizontal bars in directly opposite directions from the central post.

Hydraulic lime mortar should be mixed four parts (by measure, dry) of lime and four of sand, and wetted and ground in a ghanni in the same way as common mortar.

Concrete.—The ingredients for concrete are ballast or gravel, sand, and a cementing material, either Portland cement or lime. When good sharp river ballast can be

obtained, it will frequently be found to contain sufficient sand mixed with the stones to be ready for use; but as this is not always obtainable, broken stones or shingle have to be utilized and sand added to the whole and well mixed. Finer particles of stone are better than sand, if they can be obtained in a sufficient quantity. For cement concrete, a good proportion to adopt is, for the matrix, two parts broken stone, two parts shingle, and two parts sand. The materials can be mixed together and the volume ascertained and then an amount of cement added, which will bring the volume of matrix to cement 4 to 1, 5 to 1, 6 to 1, and so on, according to strength and quality of concrete required. 6 to 1 will make a good quality concrete for ordinary purposes. Cement concrete is much stronger by having stones in it of various sizes from the maximum downwards. The concrete should be mixed on a stage constructed of planks or boards, the materials forming the aggregate being, if necessary, previously washed. The whole mass should be turned over at least twice dry and three times after wetting, so as to become thoroughly intermixed. Water should not be splashed on from a bucket but carefully added from a large watering pot or hose fitted with a big rose, as this will facilitate the whole mass being equally wetted. In England it is becoming very general, where large masses of concrete are required, to perform the mixing in a concrete mixer. This consists of a revolving drum provided with a large manhole door. To fill the mixer, the drum is revolved until the manhole door is on the top of the drum. A definite volume of matrix is then put in, together with an ascertained quantity of water and then the proper proportion of cement is added. The manhole cover is then clipped on and the drum revolved. The manhole is finally opened when at the bottom and the concrete automatically discharges into carts or trucks. By these means absolute control is obtained over the process, and it has been found that an equally strong concrete can

be produced with a smaller proportion of cement than by hand mixing. In putting concrete in position, Engineers differ considerably as to the best thickness for each layer and the amount of consolidation, but the Author has found that in India, for ordinary purposes, if the concrete is deposited in layers of one foot and rammed or punned until the cement just begins to form a cream on the surface, it sets in a perfectly solid homogeneous mass. If the concrete, however, is to bear a heavy weight, a less thickness of layers is desirable. The surface of one layer should be thoroughly well wetted and set before adding a second layer, and if any considerable period has elapsed since the first was put down, it should be picked over to ensure a good joint. There is probably no work which requires such careful supervision as the mixing and putting in position of concrete. The materials must be thoroughly clean, and when the correctly measured amount of cement has been added, the mass must be thoroughly well turned over and the proper portion of water added; and finally, the concrete must be sufficiently, but not excessively, rammed when in position. All this can only be ensured by careful and constant supervision. It should be noted that 125 cubic feet of dry materials will form 100 cubic feet of concrete solid.

A rough and ready method of gauging the best proportions of broken stone and sand for good concrete, and one which can be adopted by any one without difficulty, is as follows:—

An ordinary bucket should be filled with broken stone, level with the top, and as much water poured in as the bucket will hold: this quantity of water represents the whole of the space between the interstices in the stones, and when poured off and measured will give the proper portion of sand to be added: the sand can then be added and the bucket refilled in the same way, and the water

again occupying the interstices will represent the minimum amount of cement to be used. In actual practice, it is advisable to keep the quantity of cement somewhat in excess of the amount gauged by this method, so as to ensure every particle of the aggregate being thoroughly cemented together. This method should be employed only so far as the stone and sand are concerned, as the former varies in size in different localities, and even if broken by hand is not always uniform. The proportion of cement should be fixed in accordance with the nature of the work and quality of concrete required. The quantity as ascertained by the method described, however, should under no circumstances be reduced, as the concrete will not otherwise be uniform or properly cemented together.

Stone for concrete should be broken to a size not larger than would pass through a 2-inch ring.

Common lime concrete should be made of one part of lime mortar and two parts of broken stone.

Hydraulic lime concrete should be made of three parts of mortar, four parts of shingle, and four parts of broken stone.

When concrete is being laid in such a position that it is to be more than two feet in thickness, it is admissible to allow rubble stones not exceeding one-half a cubic foot in size to be inserted in the concrete; but in such cases no stone should be laid nearer than nine inches from any other in any direction, nor nearer than nine inches from the surface.

Bricks.—Bricks are made of tempered clay, formed in moulds to the requisite size and shape and then burnt in a kiln. The outsides of bricks made of clay deposited with salt show dampness in humid atmosphere and require to be painted. All bricks for sanitary purposes should be made of the best quality procurable and of uniform

colour with a hard impervious surface. A simple test for hardness is that a finger nail should not be able to make a scratch or mark on the surface. The principal test for bricks is that of absorption, and Engineers generally lay down that a brick of good quality should not absorb more than 10 per cent. of its dry weight after 24 hours' immersion in water. Another test known as the crushing test is that a brick should resist the weight of 500 lbs. per square inch. All bricks should ring well when struck, be table-moulded, sound, hard, regular, well burnt and with straight sharp arrises, and should not vary from the standard size.

Stone.—Building stone is classed under three heads, namely, siliceous, argillaceous, and calcareous.

Stone is rarely used in sewerage works and the Sanitary Engineer may have little occasion to deal with this material, except for pumping stations and other buildings; but if it be found requisite, care must be taken that none with vents or flaws or traversed with seams or of perishable material should be used.

The principal kinds used in Bombay are basaltic trap or blue stone, Kurla yellow trap, both being siliceous stone, and a light coloured, building, calcareous stone known as Porbunder stone. Any of these are suitable for building. but basaltic trap is the best. The absorption of basaltic trap is very small, being 0·30 per cent. of its dry weight, while that of Kurla yellow trap is as much as 4 per cent.

Pipes.—It is not more than sixty years since earthenware glazed pipes were first used for sewers in the British Isles, but during that period their manufacture has become one of the great industries of the country.

Earthenware pipes consist of two kinds, stoneware and fire clay.

Fire clay pipes, though less brittle than stoneware pipes, are not considered, thickness for thickness, as strong

or as durable as the latter. They also usually possess great absorptive power, which is fatal to their use. Stoneware is therefore generally specified by Engineers for sewerage works.

Stoneware pipes of a greater diameter than 18 inches are rarely used, as well-shaped pipes exceeding this size are difficult to construct and are consequently expensive.

The thickness of stoneware pipes should be at least 1/12th of their diameter, and practice shews that the following are reliable proportions of thickness of material to diameter:—

Internal Diameter :	3	4	6	9	12	15	18	inches.
Thickness of material :	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	inches.

The depth of the socket should not be less than $1\frac{1}{2}$ inches for all pipes under 9 inches in diameter, 2 inches for 9-inch and 12-inch pipes, and $2\frac{1}{2}$ inches for all sizes over 12 inches. The internal diameter of the socket should be sufficiently large to allow a joint of $\frac{1}{4}$ inch all round the outside of the pipe intended to enter it, so that a caulking of tarred gasket may be inserted.

The qualifications of a good stoneware pipe are that it should be perfectly straight, truly cylindrical, thoroughly salt-glazed and burnt, and free from cracks, flaws, and defects of every description. Every pipe should be finished with a perfectly smooth interior.

The only test, short of chemical analysis, for a stoneware pipe as opposed to a fire clay one, is that of absorption. A piece of good stoneware pipe should absorb less than 2 per cent. of its own dry weight after 48 hours' immersion in water, while a fire clay pipe will absorb from 3 to 6 per cent. of its weight. Such a pipe, sooner or later, must fail on account of the action of sewage on the clay.

The impermeability of a pipe may be taken as evidence of its durability and fitness for sewerage works. The

more impervious a pipe is, the better will it prevent the entrance into its interstices of those agents which are likely to exercise a destructive influence upon it; for the chemical action of certain materials found in sewage will sooner or later destroy the pipe.

As pipes made of clay containing lime are found to fail when laid in wet ground, it is desirable to test the material of which the pipe is made. For this purpose the following method will be found satisfactory. Pulverize a small piece of the pipe, weigh and boil in hydrochloric acid; subsequently wash on a filter and dry, noting any loss in weight. If there is no loss in weight, then the material may be considered free from lime.

The other tests for a stoneware pipe aim at ascertaining its impermeability and its resistance to bursting and breaking pressures. Such pipes are specified in different ways by different Engineers.

The tests which the Author usually lays down are:—

(1) That a piece about 2 inches square from any part of the pipe shall not absorb, after 48 hours' immersion in water, more than 2 per cent. of its own dry weight of water.

(2) That the pipe shall be capable of resisting a bursting pressure of 30 lbs. per square inch.

(3) That the breaking weight of the pipe shall not be less than 1,700 lbs., applied by means of a lever or otherwise to the centre of a flat board of hard wood, of the same length as the pipe, laid along the top of the pipe throughout its length exclusive of the socket. The pipe, when subjected to this test, should be supported on a similar flat board underneath, the socket overhanging, and a layer of felt being laid between the pipe and the boards.

The salt-glazing of a pipe is a very important feature in its manufacture, for it permeates the whole of the material. Other forms of glazing often merely hide the defects of a worthless material; and some pipes, though apparently of good quality, by reason of their shape, colour, and glaze, and which also ring well, are of the worst possible material.

In England, pipes varying from 18 to 36 inches in diameter are often made of cement. Such pipes are now largely specified and used by leading Sanitary Engineers for sewerage works and they continue to grow in favour. It is desirable in the case of cement pipes to surround them with concrete, a minimum thickness of 4 inches being usually sufficient. Cement pipes have an advantage in that they can be made absolutely circular and straight. The best English Portland cement should be used in their manufacture, and that only after careful and stringent tests. In a cement pipe there is no projecting socket, the joint being contained in the thickness of the pipe itself; it is usually made with a wipe of cement.

A disadvantage of cement pipes is that junction pipes are difficult to construct, while to make a junction between a house connection pipe and a cement sewer by merely cutting a hole in the latter, is a crude and unsatisfactory piece of work. The socket also as at present made is shallow, and if the pipes are not very carefully laid, the joints are liable to separate through pressure of the earth.

An interesting failure of cement pipes has recently been brought to notice in Madras. Previous to 1902, the Madras Municipality used only stoneware pipes in their sewerage system; but early in that year they decided, on the score of economy, to use locally-made cement pipes up to 9 inches in diameter. Some five years later, these cement pipes were discovered to be in a very curious condition: that portion of the pipes which was generally

covered by sewage seemed to have stood satisfactorily, but the part exposed to sewer gas had corroded to the extent of collapse. Lieutenant-Colonel J. VanGuyzel, I.M.S., Chemical Examiner to Government, to whom the matter was referred, gives the following percentages of the corroded parts of the pipe:—

Silica	46·7
Calcium Sulphate	43·06
Uncombined Lime	0·38
Alkalides and Sulphur	0·39
Moisture	9·45

The corroded parts were occupied by a soft and easily removable substance which gave the above analysis.

Lieutenant-Colonel VanGuyzel's explanation is as follows:—

"The calcium silicate is one of the important ingre-" dients of cement. When the sulphuretted hydrogen which " is present in the sewage comes in contact with the portion " of the cement pipe which is not covered by the sewage, it " decomposes the calcium silicate and forms calcium sul-" phide and free silica. The calcium sulphide again in " the presence of moisture gets converted into calcium " sulphate and in the process deposits a small quantity of " free sulphur. This reaction accounts for the presence of " the soft substance, the chemical composition of which I " have already given."

The above explanation is very clear and is doubtless correct.

There is very little difference in the composition of good Portland cement and that of cement made in Madras as given by the published analysis.

The excess of free silica found by Colonel J. VanGuyzel is possibly due to added sand in the construction of the pipes.

Cement pipes in other parts of the world, however, have given great satisfaction and after many years use have been found in perfect condition.

4

The silicated stone pipe is another form of pipe, but it requires great care in manufacture, is expensive, and so far is not in very general favour among Sanitary Engineers.

Cast iron, though probably the best class of conduit for sewage, is too expensive for the purpose, except under special circumstances.

Patent Joint Pipes.—There are many patent jointed stoneware pipes in the market which, under certain conditions, serve a very useful purpose; but they are naturally much more expensive than ordinary stoneware pipes. The following is a description of a few of these:—

The Stanford Joint, as shewn in Fig. 5, is similar in construction to the turned spigot and faucet joints of

IMPROVED STANFORD JOINT.

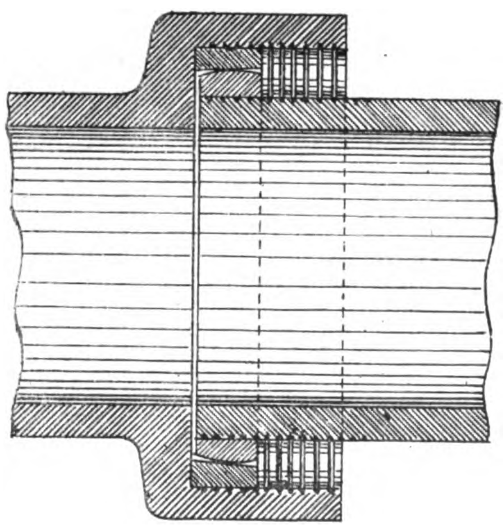


FIG. 5.

cast iron pipes, being formed of turned rings of a durable material generally consisting of a composition of sulphur,

tar, and ground earthenware. These rings, which are spherically shaped, exactly fit into each other, being counterparts; and, in order to allow of some play, the sockets are slightly concave and the spigots slightly convex. The complete joint is made by grooving the rings, and it is claimed that a perfect joint is made thereby.

Doulton & Co. have a patent self-adjusting pipe (Fig. 6.), for which it is claimed that no cement is required for jointing purposes, the grooves being merely greased or tarred.

SECTION OF SELF-ADJUSTING JOINT.

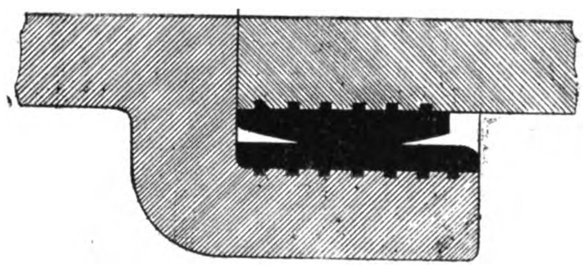


FIG. 6.

The pattern shewn in Fig. 7 is another joint manufactured by Messrs. Doulton & Co. for those who prefer to have a more steady joint.

SECTION OF COMPOSITE JOINTS.

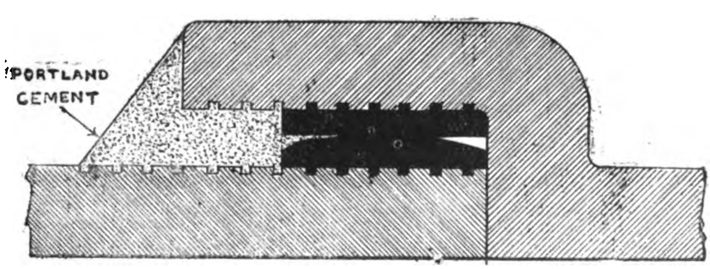
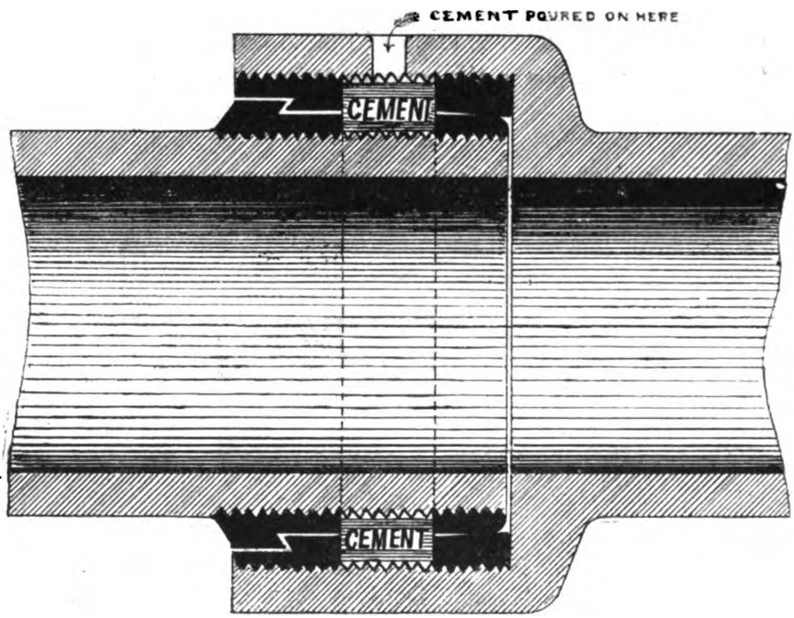


FIG. 7.

The Hassall Improved Patent Safety Joint, shown in Fig. 8, is a joint largely used. The rings are cast on with the idea of centering the pipes and retaining them in position while the operation of filling with Portland

HASSALL'S PATENT JOINT.

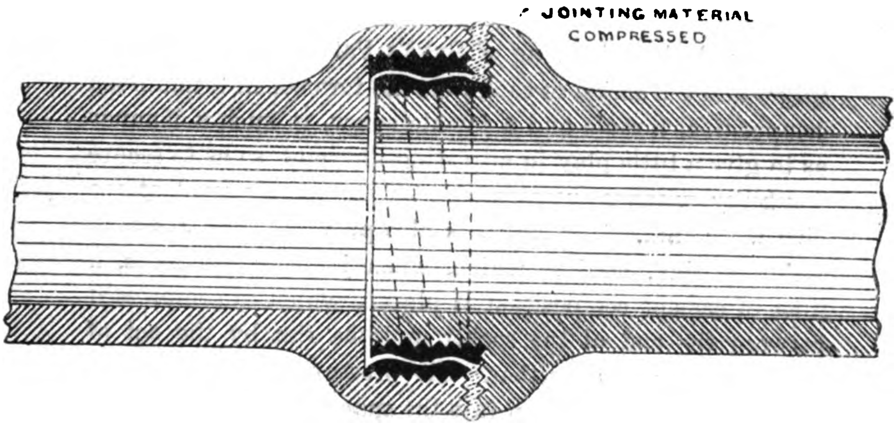


SECTION.

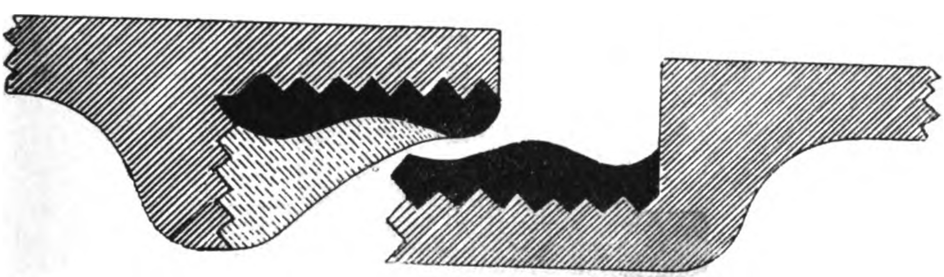
FIG. 8.

cement is being effected. Plastic is applied to the end of the spigot and between the surfaces of the bituminous rings, so as to have a cushion to embed them and render harmless any grit that may have got there and to prevent the cement from running into the pipe. The groove is filled with Portland cement. This is a good joint and has successfully stood the test of several years. Many pipe-makers

SYKE'S PATENT JOINTS.



BEFORE JOINTING.



AFTER JOINTING.

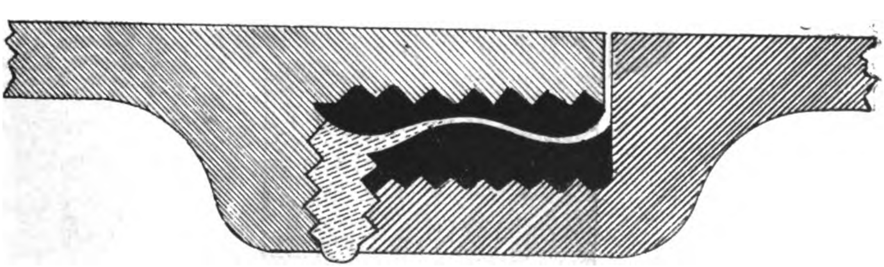


FIG. 9.

in England hold a license to manufacture pipes on this principle.

Fig. 9 is a drawing of Syke's Patent Joints. On the spigot and the socket of each pipe are formed, in bituminous composition, a male and a female screw, in such a manner as to give a little play in adjusting the joint, so as to secure flexibility without interfering with the proper level of the pipe when laid. The spigot is also provided with a strong collar or ring, against which, when jointing the pipes, a fillet of cement composition is placed, which is compressed between the end of the socket and the rim by the act of screwing the pipes together. The pressure forces the superfluous cement composition into the space left for play in the thread. It is claimed that these joints have stood an hydraulic test of 140 lbs. per square inch without leaking. The pipes are made by the Albion Clay Company.

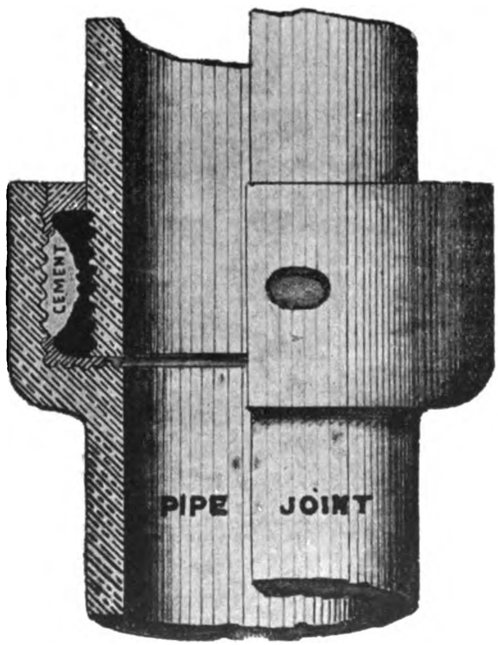


FIG. 10.

One of the most recent patent joints adopted for stoneware drain pipes has been introduced by Mr. John Parker and is known as Parker's Safety Pipe Joint (Fig. 10). This joint has only one composition ring instead of two, as is common to most patent joints, thus reducing the cost. The method of jointing is as follows:—The collar has a cushion of tempered clay which receives and embeds the composition ring on the spigot end, making it water-tight while the cement is poured into the annular groove. The band of tempered clay round the mouth of the socket after the pipes are in position, prevents the Portland cement from escaping outwards.

The Sutton Patent Joint (Fig. 11) is in many ways similar to the Hassall, but it is said to be a slight

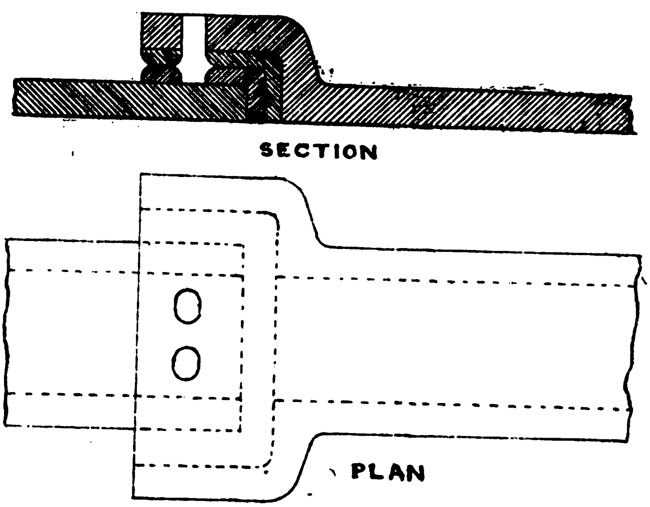


FIG. 11.

improvement on it. In this joint also plastic is used, but the liquid cement is pumped in through one of the two openings in the socket of the pipe by means of a simple and cheap hand-pump, until it appears through the other

opening, when the joint may be considered to be successfully made.

Pipes with the last described joint have been used with success in Bombay in positions where, owing to running water in the trenches, it would have been impossible to make the ordinary cement joint with safety. Pipe layers in India are very conservative and have a strong objection to these patent joints, but after a little practice they are able to make two joints with patent pipes in the time they would require to complete one ordinary joint.

Wherever trenches are water-logged and cannot be kept free of water, an Engineer does wisely to spend the extra money in using good special joint pipes, being thus assured of good water-tight joints and running no risk of permanently leaky joints.

In Eastern countries, where the Banyan tree (*Ficus Indica*) is largely grown for its shade along road sides and streets, much trouble is avoided by the use of patent jointed pipes, for the roots of the Banyan cannot be prevented by ordinary cement-joints alone from piercing the pipes in their search for water. The mixture of tar and cement, which is sometimes used for jointing sewers in streets where Banyan trees flourish, has only been partially successful in Bombay; but no Banyan root can find its way through a patent joint pipe, such as Hassall's or Sutton's.

It is difficult to say which of the patent joint pipes above described is the best. Those in which cement is used in combination with bituminous composition are superior to those used with bituminous composition only, and of them all the Author favours the Hassall, the Sutton, or the Parker, the Sutton and the Parker being the simplest and the most easily workable by pipe layers in the East.

Sewers.—A drainage system and its sewage outfall having been decided on, it is necessary, in order that the

capacity of the sewers may be determined, to ascertain the head of its water supply.

The method usually adopted for calculating the future population of any area is to ascertain what the past rate of increase or decrease has been for a cycle of years and then to make the same, or in some cases—according to local circumstances—a greater or less allowance for the probable increase or decrease in the future. The recent census, which has been taken all over India and which is admittedly the most complete yet made, lightens this task for the Indian Sanitary Engineer, and makes the work of calculating the present and prospective population a comparatively easy one.

Population affects sewerage works, inasmuch as each individual member of the community uses a certain amount of water and contributes a certain amount of solid matter to the sewers. The quantity of water supplied daily to any area is generally discovered without difficulty ; but it varies considerably between the mofussil town, with its well-supply of from 5 to 7 gallons per head, and a City like Bombay, with its lakes and pipes capable of supplying 40 gallons per head per day. In the latter class of cases, the Engineer should allow for 6 cubic feet of sewage per head per day, half to flow off in 8 hours.

Given the water supply per head and the population of any area, the required capacity of its sewers is then easily determined. If the population is 10,000 and the water supply 20 gallons per head per diem, the sewers must be capable of conveying daily 200,000 gallons to the sewage outfall. But, owing to the fact that in Eastern as well as in other countries the largest amount of water is used in the early morning, one-half of the average daily supply should be assumed to flow off within 8 hours, so that the sewer capacity should be made capable of convey-

ing 100,000 gallons in 8 hours, equal to 12,500 gallons per hour, or 208 gallons per minute, at the time of maximum flow.

The minimum velocity of sewage, usually held to be sufficient for satisfactory self-cleansing in England, may be taken at 2 feet per second ; but a greater velocity than this is usually allowed for, especially on small sewers up to 12 inches in diameter. A velocity of 2 feet per second has been found to be insufficient for India, and after considerable experience, the Author is of opinion that in this country a minimum velocity of 3½ feet per second should be taken for all sewers, on account of the heaviness of some of the foreign matter in the sewage. It is essential that every sewer should be of such dimensions and laid at such a gradient, that the volume of sewage delivered to it will always be of a depth within it sufficient to maintain the given velocity.

The formula used and published in tables and diagrams for use in designing sewers and water mains by Messrs. W. Santo Crimp and C. Ernest Bruges has been found to be reliable. It was devised by Messrs. Crimp and Bruges after experiments carried out on the London sewers. The results of the formula closely follow the results obtained from the well-known Kutter formula, which is, however, cumbersome and laborious to work out. By adjusting the co-efficient given in the formula, viz., 124, the results obtained may be made to correspond with Kutter's formula for different co-efficients of roughness. The co-efficient 124 corresponds with Kutter's N= ·012. The formula may be confidently used in the design of drainage works, in which stoneware pipes and brickwork of good quality are to be employed. It is as follows:—$v = 124 \sqrt[3]{r^2} \sqrt{s}$

Where v = Velocity in feet per second.
r = Hydraulic mean depth in feet.
s = Fall divided by the length.

For circular pipes running full or half full, this is equivalent to $V = \frac{563 \sqrt{D}}{\sqrt{I}}$, and $Q = \frac{3 \cdot 072 \sqrt[3]{D^8}}{\sqrt{I}}$

Where V = Velocity in feet per minute.

D = Diameter in inches = 48 r.

I = Inclination or the length divided by the fall = $\frac{1}{s}$:

Q = Cubic feet per minute delivered when running full.

The following example illustrates the working of the formula:—

Find, for example, the velocity and discharge of a 9-inch pipe sewer at a gradient of 1 in 200.

$$r = \frac{\cdot 75}{4} = \cdot 19 \text{ nearly.}$$

$$\therefore \sqrt[3]{r^2} = \cdot 3305.$$

& $v = 124 \times \cdot 3305 \times \sqrt{\frac{1}{200}} = \frac{40 \cdot 94}{14 \cdot 14} = 2 \cdot 89$ feet per second ; or thus

$$V = \frac{563 \sqrt[3]{81}}{\sqrt{200}} = 172 \text{ feet per minute.}$$

and Q= $\cdot 4418 \times 172 = 76$ cub. feet per minute.

This result, as will be seen from the foregoing remarks, shews that the gradient is not sufficiently steep for a 9-inch pipe sewer.

In the same way, with the above formulæ, the velocity and the discharge of any sewer can be calculated.

As already stated there is a limit to the maximum velocity of flow in sewers, because of the solid matter in the sewage which tends to wear away the inside surface of the sewers. Several authorities, including Rankine and Rawlinson, limit this velocity to 4½ feet per second, which, in the opinion of the Author, is a low limit; but in deciding such a question, the quality of the sewage to be dealt with must be considered. In Bombay, the sewage contains a large quantity of road detritus, derived from the basaltic rock with which all the roads are macadamised. In such sewage a maximum velocity of 5 per second should be given, but in ordinary domestic sewage 6 feet per second may be allowed without danger.

The modern practice in sewerage schemes is to use pipes and sewers of relatively much smaller diameters than those used in former years, and this more especially refers to pipe sewers. It has often been found with pipes laid years ago that they have never ordinarily carried more than 1-5th of their full capacity and it is manifestly more economical in such cases to use pipes of a smaller diameter. Other considerations, however, impose a limit on a minimum size, and it is not advisable to lay any pipe sewer of a less diameter than 8 inches, even though calculations based on the formula already quoted might shew that a pipe of much smaller capacity would do all the work required. The practice in Bombay in past years has been to lay pipe sewers of 9 inches in diameter as a minimum, but this is somewhat large.

Small sewers require a greater inclination than larger ones, and pipe sewers require less inclination than brick sewers.

For ready reference, certain tables are here inserted, calculated from the formulæ already given.

Table I gives the value of $\sqrt[3]{r^2}$ for different values of "r" from ·01 to ·3.

TABLE I.

GIVING THE VALUE OF $\sqrt[3]{r^2}$

r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$	r.	$\sqrt[3]{r^2}$
		·30	·4481	·60	·7114	·90	·9322	1·20	1·129	1·50	1·310	1·80	1·480	2·10	1·640	2·40	1·793	2·70	1·939
·01	·0464	·31	·4580	·61	·7193	·91	·9391	1·21	1·136	1·51	1·316	1·81	1·485	2·11	1·645	2·41	1·798	2·71	1·944
·02	·0737	·32	·4678	·62	·7271	·92	·9459	1·22	1·142	1·52	1·322	1·82	1·491	2·12	1·650	2·42	1·803	2·72	1·949
·03	·0965	·33	·4775	63	·7349	·93	·9528	1·23	1·148	1·53	1·328	1·83	1·496	2·13	1·656	2·43	1·808	2·73	1·953
·04	·1170	·34	·4871	·64	·7427	·94	·9596	1·24	1·154	1·54	1·334	1·84	1·502	2·14	1·661	2·44	1·813	2·74	1·958
·05	·1357	·35	·4966	·65	·7504	·95	·9664	1·25	1·160	1·55	1·339	1·85	1·507	2·15	1·666	2·45	1·818	2·75	1·963
·06	·1533	·36	·5061	·66	·7581	·96	·9732	1·26	1·167	1·56	1·345	1·86	1·513	2·16	1·671	2·46	1·822	2·76	1·968
·07	·1699	·37	·5154	·67	·7657	·97	·9799	1·27	1·173	1·57	1·351	1·87	1·518	2·17	1·676	2·47	1·827	2·77	1·973
·08	·1857	·38	·5246	·68	·7733	·98	·9866	1·28	1·179	1·58	1·357	1·88	1·523	2·18	1·681	2·48	1·832	2·78	1·977
·09	·2008	·39	·5338	·69	·7809	·99	·9933	1·29	1·185	1·59	1·362	1·89	1·529	2·19	1·686	2·49	1·837	2·79	1·982
·10	·2154	·40	·5429	70	·7884	1·00	1·000	1·30	1·191	1·60	1·368	1·90	1·534	2·20	1·692	2 50	1·842	2·80	1·987
·11	·2296	·41	·5519	·71	·7959	1·01	1·007	1·31	1·197	1·61	1·374	1·91	1 540	2·21	1·697	2·51	1·847	2·81	1·991
·12	·2433	·42	·5608	·72	·8033	1·02	1·013	1·32	1·203	1·62	1·379	1·92	1·545	2·22	1·702	2·52	1·852	2·82	1·996
·13	·2566	·43	·5697	·73	·8107	1·03	1·020	1·33	1·210	1·63	1·385	1·93	1·550	2·23	1·707	2·53	1·857	2·83	2·001
·14	·2696	·44	·5785	·74	·8181	1·04	1·026	1·34	1·216	1·64	1·391	1·94	1·556	2·24	1·712	2·54	1·862	2·84	2·005
·15	·2823	·45	·5872	·75	·8255	1·05	1·033	1·35	1·222	1·65	1·396	1·95	1·561	2·25	1·717	2·55	1·867	2·85	2·010
·16	·2947	·46	·5959	·76	·8328	1·06	1·040	1·36	1·228	1·66	1·402	1·96	1·566	2·26	1·722	2·56	1·871	2·86	2·015
·17	·3069	·47	·6045	·77	·8401	1·07	1 046	1·37	1·234	1 67	1·408	1·97	1·572	2·27	1·727	2·57	1·876	2·87	2·019
·18	·3188	·48	·6130	·78	·8474	1·08	1·053	1·38	1·240	1·68	1·413	1·98	1·577	2·28	1·732	2·58	1·881	2·88	2·024
·19	·3305	·49	·6215	·79	·8546	1·09	1·059	1·39	1·246	1·69	1·419	1·99	1·582	2 29	1·737	2·59	1·886	2·89	2·029
·20	·3420	·50	·6300	·80	·8618	1·10	1·066	1·40	1·252	1·70	1·424	2·00	1·587	2·30	1·742	2·60	1·891	2·90	2·034
·21	·3533	·51	·6384	·81	·8690	1·11	1·072	1·41	1·257	1·71	1·430	2·01	1·593	2·31	1·748	2·61	1·896	2·91	2·038
·22	·3644	·52	·6467	82	·8761	1·12	1·078	1 42	1·263	1·72	1·436	2·02	1·598	2·32	1·753	2·62	1 901	2·92	2·043
·23	·3754	·53	·6550	·83	·8832	1·13	1 085	1·43	1·269	1·73	1·441	2·03	1·603	2·33	1·758	2·63	1·905	2·93	2·048
·24	·3862	·54	·6632	·84	·8903	1·14	1·091	1·44	1·275	1·74	1·447	2·04	1·609	2·34	1·763	2·64	1 910	2·94	2·052
·25	·3969	·55	·6714	·85	·8973	1·15	1·098	1·45	1·281	1 75	1·452	2·05	1·614	2·35	1·768	2·65	1·915	2·95	2·057
·26	·4074	·56	·6795	·86	·9043	1·16	1·104	1·46	1·287	1·76	1·458	2·06	1·619	2·36	1·773	2·66	1·920	2·96	2·062
·27	·4178	·57	·6875	·87	·9113	1·17	1·110	1·47	1·293	1·77	1·463	2·07	1·624	2·37	1 778	2·67	1·925	2·97	2·066
·28	·4280	·58	·6955	·88	·9183	1·18	1·117	1·48	1·299	1·78	1·469	2·08	1·630	2·38	1·783	2·68	1·929	2·98	2·071
·29	·4381	·59	·7035	·89	·9253	1·19	1·123	1·49	1·305	1·79	1·474	2·09	1·635	2·39	1·788	2·69	1·934	2·99	2·076
·30	·4481	·60	·7114	·90	·9322	1·20	1·129	1·50	1·310	1·80	1·480	2·10	1·640	2·40	1·793	2·70	1·939	3·00	2·080

Table II gives the areas in square feet of circular sewers and pipes, mostly used in sewerage works, and the value of $\sqrt[3]{r^2}$ when running full.

Table III gives the areas of the principal egg-shaped sewers in square feet and the value of $\sqrt[3]{r^2}$ when running full, two-thirds full and one-third full.

Table IV gives the gradients at which different sizes of pipe sewers should be laid to give different velocities, when running full or half full.

Table V gives the gradients at which different sizes of ovoid sewers should be laid to give different velocities when running full.

TABLE II.

AREAS OF CIRCULAR SEWERS AND PIPES IN SQUARE FEET AND THE VALUE OF $\sqrt[3]{r^2}$ WHEN RUNNING FULL.

(*r = Hydraulic mean depth in feet.*)

Diameter in inches.	Area in square feet (full).	$\sqrt[3]{r^2}$
4	·0873	·1908
6	·1963	·2500
7	·2672	·2771
8	·3491	·3029
9	·4418	·3276
10	·5454	·3514
12	·7854	·3969
15	1·2272	·4605
18	1·7671	·5200
21	2·4053	·5763
24	3·1416	·6300
27	3·9761	·6814
30	4·9087	·7310
33	5·9396	·7790
36	7·0686	·8255

TABLE III.

AREAS OF EGG-SHAPED SEWERS (OLD FORM) IN SQUARE FEET AND THE VALUE OF $\sqrt[3]{r^2}$

(r = *Hydraulic mean depth in feet.*)

Size.					Full.		Two-thirds full		One-third full.	
Width.			Height.		Area in square feet.	$\sqrt[3]{r^2}$	Area in square feet.	$\sqrt[3]{r^2}$	Area in square feet.	$\sqrt[3]{r^2}$
Ft.	In.		Ft.	In.						
1	8	×	2	6	3·1903	·6154	2·0994	·6518	·7889	·4912
2	0	×	3	0	4·5940	·6950	3·0232	·7360	1·1860	·5548
2	4	×	3	6	6·2529	·7702	4·1149	·8156	1·5462	·6147
2	6	×	3	9	7·1781	8064	4·7237	·8540	1·7750	·6437
2	8	×	4	0	8·1671	·8419	5·3746	·8915	2·0195	·6720
3	0	×	4	6	10· 337	·9107	6·8022	·9644	2·5560	·7269
3	4	×	5	0	12· 761	·9770	8·3978	1·0346	3·1556	·7799
3	6	×	5	3	14· 069	1·0092	9·2585	1·0688	3·4790	·8056
3	10	×	5	9	16· 877	1·0734	11· 106	1·1356	4·1732	·8560
4	0	×	6	0	18· 376	1·1032	12· 093	1·1683	4·5440	·8806
4	6	×	6	9	23· 257	1·1933	15· 305	1·2637	5·7510	·9526
4	8	×	7	0	25· 012	1·2226	16· 460	1·2948	6·1849	·9759
5	4	×	8	0	32· 668	1·3365	21· 498	1·4152	8·0782	1·0668
6	0	×	9	0	41· 346	1·4457	27· 209	1·5309	10·0224	1·1540

TABLE IV.

RATES OF INCLINATION OF CIRCULAR SEWERS TO GIVE THE FOLLOWING VELOCITIES WHEN RUNNING FULL OR HALF-FULL.

Velocity in feet per second.	Diameter 4 in.	Diameter 6 in.	Diameter 7 in.	Diameter 8 in	Diameter 9 in.	Diameter 10 in.	Diameter 12 in.	Diameter 15 in.	Diameter 18 in.	Diameter 21 in	Diameter 24 in.	Diameter 27 in.	Diameter 30 in.
2	1 in 140	1 in 240	1 in 295	1 in 350	1 in 415	1 in 475	1 in 610	1 in 820	1 in 1050	1 in 1275	1 in 1525	1 in 1775	1 in 2050
2½	1 in 89	1 in 155	1 in 190	1 in 225	1 in 265	1 in 305	1 in 385	1 in 520	1 in 660	1 in 820	1 in 970	1 in 1138	1 in 1315
3	1 in 62	1 in 105	1 in 130	1 in 155	1 in 185	1 in 210	1 in 270	1 in 365	1 in 460	1 in 570	1 in 680	1 in 790	1 in 910
3½	1 in 46	1 in 78	1 in 96	1 in 115	1 in 135	1 in 155	1 in 200	1 in 265	1 in 340	1 in 415	1 in 500	1 in 585	1 in 670
4	1 in 35	1 in 60	1 in 73	1 in 88	1 in 105	1 in 120	1 in 150	1 in 205	1 in 260	1 in 320	1 in 380	1 in 445	1 in 515
4½	1 in 28	1 in 47	1 in 58	1 in 70	1 in 82	1 in 94	1 in 120	1 in 160	1 in 205	1 in 250	1 in 300	1 in 352	1 in 405
5	1 in 22	1 in 38	1 in 47	1 in 56	1 in 66	1 in 76	1 in 97	1 in 130	1 in 165	1 in 205	1 in 245	1 in 285	1 in 330
5½	1 in 19	1 in 32	1 in 39	1 in 47	1 in 55	1 in 63	1 in 80	1 in 105	1 in 138	1 in 170	1 in 200	1 in 234	1 in 270
6	1 in 16	1 in 27	1 in 33	1 in 39	1 in 46	1 in 53	1 in 67	1 in 91	1 in 115	1 in 140	1 in 170	1 in 197	1 in 230

TABLE V.

RATES OF INCLINATION OF OVOID SEWERS (OLD FORM) TO GIVE THE FOLLOWING VELOCITIES WHEN RUNNING FULL.

Velocity in feet per second.	2′—0″ × 3′—0″	2′—6″ × 3′—9″	2′—8″ × 4′—0″	3′—0″ × 4′—6″	3′—4″ × 5′—0″	3′—10″ × 5′—9″	4′—0″ × 6′—0″	4′—8″ × 7′—0″	5′—4″ × 8′—0″
2	1 in 1850	1 in 2500	1 in 2725	1 in 3200	1 in 3650	1 in 4400	1 in 4700	1 in 5800	1 in 6890
2½	1 in 1200	1 in 1600	1 in 1750	1 in 2050	1 in 2350	1 in 2825	1 in 3000	1 in 3700	1 in 4400
3	1 in 825	1 in 1100	1 in 1200	1 in 1400	1 in 1634	1 in 1950	1 in 2075	1 in 2550	1 in 3050
3½	1 in 600	1 in 815	1 in 900	1 in 1050	1 in 1200	1 in 1450	1 in 1525	1 in 1875	1 in 2250
4	1 in 460	1 in 625	1 in 685	1 in 800	1 in 900	1 in 1100	1 in 1175	1 in 1440	1 in 1700
4½	1 in 355	1 in 500	1 in 538	1 in 630	1 in 725	1 in 875	1 in 925	1 in 1130	1 in 1350
5	1 in 300	1 in 400	1 in 435	1 in 500	1 in 590	1 in 700	1 in 750	1 in 910	1 in 1100

Construction.—It is most necessary that sewers should be laid straight and true with a regular and uniform gradient. Too much importance cannot be attached to this; for once the sewer is laid and the trench filled in, it is lost to view and inequalities in gradients are not easily detected. The proper laying of the sewer can only be ensured by the use of sight rails and boning rods. Sight rails consist of two uprights fixed on either side of the trench with a straight cross rail attached to them horizontally: they are placed at convenient distances along the line of the sewer and the levels of the cross rails are so fixed that their upper edges are on a plane parallel to the gradient of the sewer and at a constant height from its bed. If the boning rod (the head of which is like a T square) of a length equal to the above height is moved along the line of sight between the two sight rails, the lower end determines the level of the invert of the sewer. Three sight rails rather than two should be used for one stretch of a sewer, and they should be constantly checked to see that they have neither settled nor been moved. In laying pipes, care should be taken that they are laid on an even bearing; for, if laid on a point of rock, sooner or later they will fracture and possibly subside, and at any rate will allow sewage to soak into the soil. If laid on a rocky foundation, it is advisable to bed the pipes on an even cushion of 2 inches or so of muram.

In drainage contracts, it will be found satisfactory, where ground is of uncertain quality, to lay down in the specification that the width of the trench which will be measured for 9-inch pipe sewers shall be 3 feet. A general rule may, however, be adopted that all trenches shall be at least 2 feet wider than the greatest diameter of the pipe.

The sides of the trench should be carefully secured and shored, whenever the excavation has to be carried to a great depth. No hard and fast rule can be laid down for

the maximum depth to which the excavation should be carried without the trench being shored, as this entirely depends on the character of the soil, and on the latter also depends the kind of shoring to be adopted. In reclaimed ground, it will be found dangerous to excavate deeper than three or four feet without shoring ; while in good muram, a trench can be dug to a depth of seven or eight feet without any necessity for protection against collapse. Subsoil water also governs this question. A dry soil which will stand without shoring will require, if there is subsoil water running into the trench, to be shored. Of all excavations, the worst and the most difficult is that of running sand. When excavations exceed a depth of 16 feet or so, it may be found cheaper in good ground to tunnel or, in other words, to run a heading. Three principal kinds of shoring may be adopted, and are shewn in Figs. 12, 13, and 14.

In Fig. 12 the shoring is of the simplest kind. The timbering in this case, if it slips at all, must tighten up against the side of the trench, the excavation being wider at the top than at the bottom. The walings (W) are kept in position by struts (S), and props (B) are in some cases added. In instances where it is desired to support a large surface of ground, poling boards (P) are put in as in Fig. 13. In bad ground, close shoring, as in Fig. 14, is necessary and the poling boards are used as runners. In such shoring the struts should be of as great a diameter as possible; for, if small, they have a tendency to split the walings: the distances between them vertically should be about 5 feet.

It is necessary for the proper and efficient execution of sewerage works that the trenches or excavations should be quite dry, and pumping must therefore be employed wherever water is met with. No masonry should be built, no concrete deposited, and no pipe joints made in water. The water must be kept down by the pumps to below the level of any work, and pumping continued until and as long as may be necessary for the cement to have set hard.

METHODS OF SHORING TRENCHES.

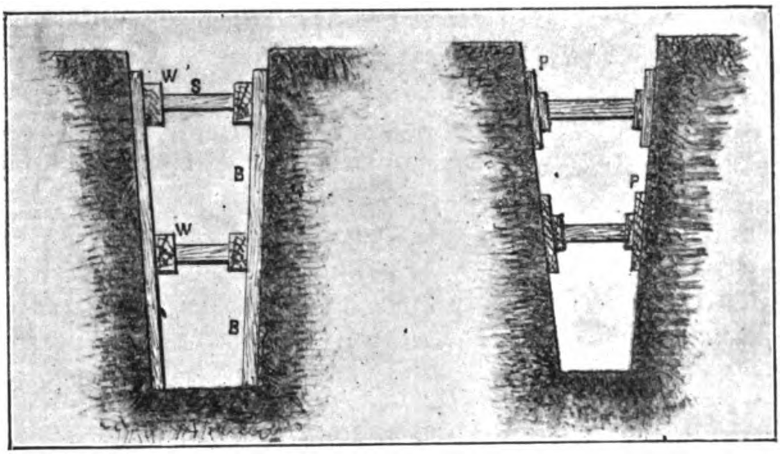


FIG. 12. FIG. 13.

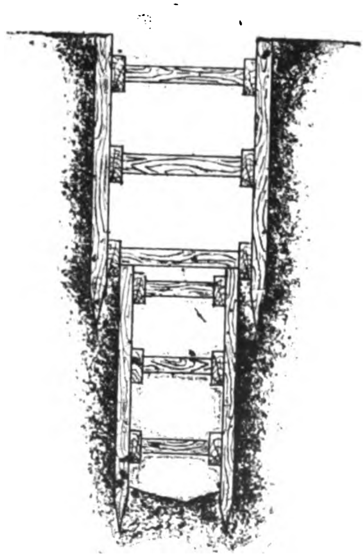


FIG. 14.

If the bottom of the trench is soft and muddy, it is unsuitable for sewerage works without additional foundation being provided to carry the pipe or sewer. The best expedient to be adopted in such cases is to cause dry rubble to be rammed in the bottom of the trenches as deep as possible, and on this bedding of stones the sewer should be laid or constructed with a layer of good muram or concrete between.

Ovoid Sewers.—Fig. 15 shews the section of an ovoid or egg-shaped sewer, 2 feet 6 inches by 3 feet 9 inches. The invert of the sewer is formed of blocks of cement concrete, carefully and properly moulded in boxes to the form and dimensions required. The concrete for the blocks is composed by measure in the proportion of one part of cement, two parts of sand, and two parts of clean river shingle. The concrete, as soon as mixed, is filled into the mould boxes and well rammed. The blocks should remain in the moulds for two days and be kept well moistened with water. They are then taken out and kept in the shade for two or more days before they are used in the work. The blocks should be laid as close together as possible and the joints should be filled in with neat cement mixed to the consistency of cream.

The excavation for an ovoid sewer between the invert and the springing line should, as far as practicable, be cut to the shape of the sewer. The walls of the ovoid sewer, between the invert and the springing line, may be constructed of cement concrete deposited and well rammed between the sides of the trench, shaped as already described, and a centering formed to the true internal shape of the sewer allowing half an inch for a facing of cement plaster. After the concrete is set and the centering removed, the internal face is rendered with cement and sand mixed in the proportion of one to one. The covering arch is also formed of cement concrete, rammed *in situ* and plastered on the inside with cement.

In the new form of ovoid sewer, the vertical height is one-and-a-half times the transverse diameter, *i.e.*, three times the radius of the covering arch. The invert is struck from a centre on the vertical height with a radius equal to one-eighth of the transverse diameter, and the sides are

SECTION OF OVOID SEWER 2′-6″ × 3′-9″

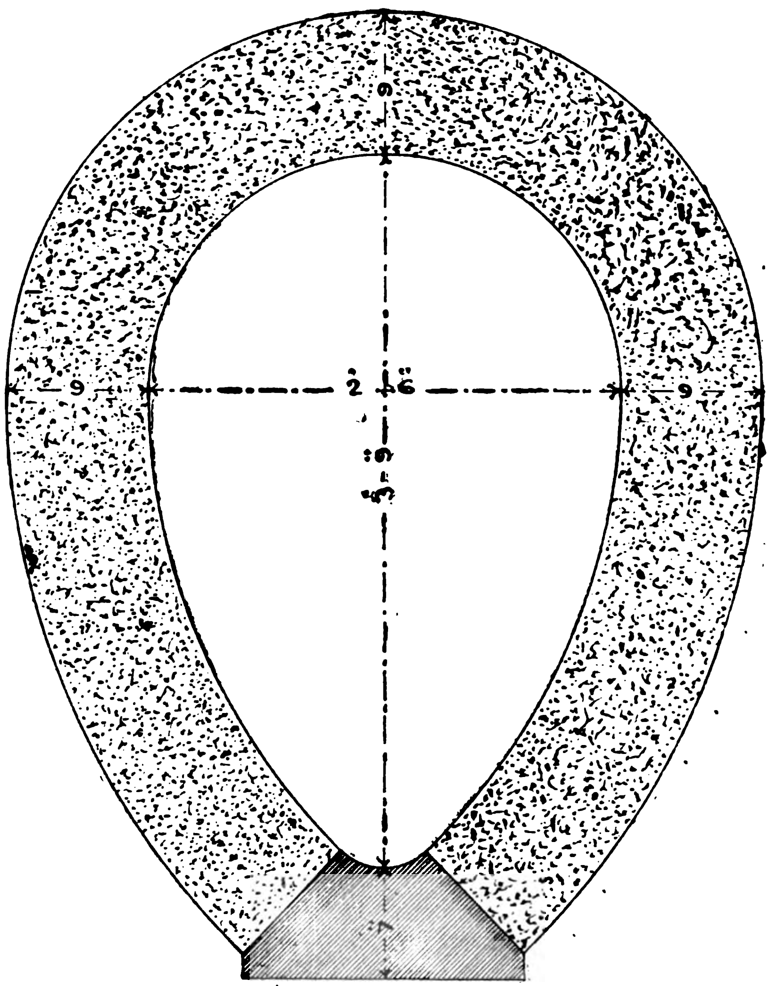


FIG. 15.

struck from centres on the prolongations of the transverse diameter with a radius equal to one-and-a-third times the length of that diameter; while in the old form of ovoid sewer, the radius of the invert is one-fourth of the transverse diameter and that of the sides one-and-a-half times the transverse diameter.

Another not unusual construction for ovoid sewers is that of double brickwork set and rendered in cement as shewn in Fig. 16. In this class of sewer, concrete blocks are also advisable for the invert. A simple formula for ascertaining the thickness of brickwork required is:—

d=depth of excavation in feet
r=the external radius of the sewer in feet.

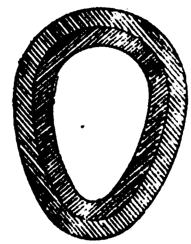


FIG. 16.

Then the thickness of the brickwork in feet is $\frac{d\,r}{100}$.

An allowance of 50 per cent. should be made on the results of this formula for Indian made bricks, because such bricks are generally much inferior to English, both in shape and quality. For this reason cement plastering, both on the inside and the outside of sewers built with Indian bricks, is necessary to finish the sewer off with an even face, unless concrete is used as a cover or hood, and then cement plastering only on the inside is required. With English bricks, only pointing of the inside face is necessary. With ovoid sewers built with Indian bricks of a size 2 feet 6 inches by 3 feet 9 inches in solid ground not exceeding 20 feet in depth, the thickness of the sewer should be two bricks thick or one brick with a hood of 6 inches of lime concrete. For sewers not exceeding 4 feet in diameter, the thickness should be of two bricks with a cover of 6 inches of lime concrete, the thickness of the brickwork increasing proportionately to the size of the sewer.

Fig. 17 shews an ovoid sewer only one brick thick, enclosed entirely with concrete. This type is useful in indifferent ground and at considerable depths.

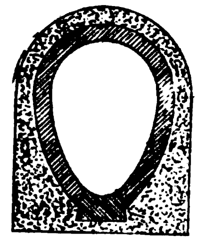


FIG. 17.

In some sewers constructed of concrete the arch is formed of concrete voussoirs, as shewn in Fig. 18. The voussoirs are made in moulds in the same way as the blocks described in regard to Fig. 15. This is a useful construction of sewer and is recommended in bad ground on account of its strength.

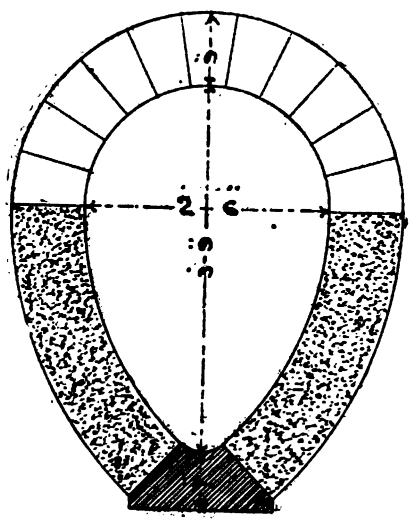


FIG. 18.

Fig. 19 shews another type of ovoid sewer, known as the new egg-shaped, and is for use in gravel or running sand. The invert blocks may be of concrete or stoneware. It will be noticed here that the lower half of this sewer is well protected with a covering of cement concrete.

In recent years circular brick sewers have found greater favour among Engineers than ovoid or egg-shaped sewers. There are several reasons for this, the principal being that circular sewers of a large size are rarely called upon to deal with so little sewage as to make an egg-shaped sewer of similar capacity advantageous Again, the length of the wetted perimeter of a circular sewer is, with equal volumes of sewage, less than that of an egg-shaped sewer: circular sewers are also usually more economical in construction.

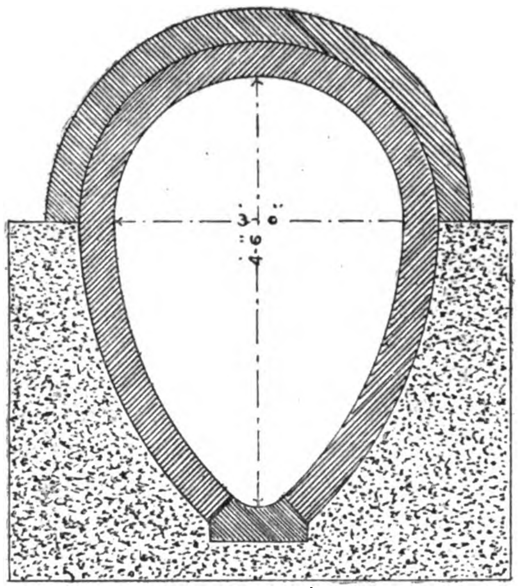


FIG. 19.

Stoneware junction blocks, of the shape shewn in Fig. 20, are inserted in the wall of the sewers above springing level, wherever required, for connections of house drains.

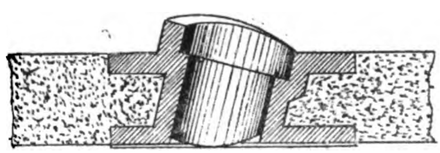


FIG. 20.

Plate 3 shews a design for manholes for ovoid sewers. These may be built either of concrete or of brickwork set in cement or hydraulic mortar, and rendered both internally and externally with cement plaster. Cast-iron steps are

inserted in the manhole, so as to give access to the sewer when required, with a notch in the wall in lieu of the last step, as any projection at this level would be liable to catch rags, etc., and cause obstruction to the flow of sewage. In certain manholes a groove is left in the invert and walls for flushing purposes as shewn in Plate 3. Into this groove a wooden door is let down and kept there until sufficient sewage is dammed up to give a good flush. The manholes are covered with cast iron frames and covers as hereinafter described.

Laying and Jointing of Stone-ware Pipe Sewers.—Pipes should not be laid at too great a depth without a protection of concrete designed to resist the pressure of the covering material. A depth of 15 feet to 16 feet is recommended as the limit for 9-inch pipes and 12 feet for all larger sizes; and all pipes laid at these or greater depths should be laid on and covered with a layer of 6 inches of lime or cement concrete. Pipes which are laid at a shallow depth may also require a protection of concrete to prevent rupture by the weight of heavy traffic.

It is a good rule to follow that the minimum depth at which a pipe sewer should be laid should be equal to three times the diameter of the pipe. If circumstances are such that this rule cannot be followed and the sewer must be laid at a less depth, a cast iron pipe should be used.

In the laying of pipe sewers, the pipes should be first laid and fitted dry, previous to the jointing being commenced, such junctions being inserted as may be required for house drainage connections. Pipes should then be plumbed and boned to ensure their being truly laid both to line and gradient.

In earlier years, earthenware pipes were jointed merely with clay, and even at the present day this practice is to a certain extent continued. No worse material than clay can be found for jointing pipes; for a soft yielding sub-

stance of this description is almost certain to be washed out of the joint either by water escaping from the pipes or by the subsoil water flowing alongside the pipe. Moreover, a material such as clay, is sure to be pressed from the joint by the weight of the earth covering the pipe. Clay also offers no barrier to roots entering the pipe through the joint.

Stoneware pipes for conveying sewage should always have their joints composed of cement mortar, *i.e.*, one of cement and one of fine sand. The process of jointing should be as follows:—A gasket of hemp, well-tarred and cut in lengths sufficient to pass completely round the spigot end of the pipe, is driven well home into the base of the socket, care being taken that not more than a quarter of the depth of the socket is taken up by each gasket. Portland cement mortar is then forced into the joint until the whole space round the spigot between it and the socket is quite full. The joint is then finished off with a neatly splayed fillet of pure cement. Each joint should be carefully examined in the inside of the pipe, and any cement that has oozed through should be carefully smoothed off.

When there is much water in a sewer trench, it is a good plan to protect the pipe joint by means of a piece of cloth tied around each joint.

After all the joints have been carefully made and before the trench is filled in, what are known as the "disk test" and the "water test" should be applied to each length of pipes between manhole and manhole.

The former test consists in passing a cylinder of wood. about half an inch less in diameter than the pipe, through the whole length of the sewer to ensure its being clear of rubbish.

The latter test consists of closing the lower end of the pipe and filling it entirely with water, until a head of at least 12 inches is obtained in the upper manhole. If there

is no fall in the level of the water after two hours, it may be taken that the joints have been well made and are water-tight, and the particular length of the pipes tested may be passed. This is an important test, which should never be omitted and should always be made while the pipes are exposed.

Plate 4 gives the details of circular manholes on pipe sewers, which are constructed on lines of sewers for the purpose of inspection and cleansing: they should not be more than 200 feet apart, and the sewer should always be laid straight between manhole and manhole, so as to facilitate inspection and cleansing and to ensure there being no gaps or spaces in the joints of the pipes.

Manholes are generally constructed of brickwork set in cement and, though usually rectangular or circular, may be of any shape. The thickness of the brickwork will vary, according to depth, from 18 to 9 inches. A manhole should usually be founded on a 12-inch layer of cement concrete. In the case of rock, this may be reduced to 6 inches. The circular shape has found most favour in Bombay, since, on the removal of the cover, the inspection of the whole of the floor can be at once made. Circular manholes will vary in their vertical section according to the depth and the class of soil in which they are constructed, the dome shaped section being recommended for depths up to 5 feet 6 inches and the conical shape for greater depths. The top and bottom of manholes are the same in size for all depths. The sides of a conical shaped manhole at a depth less than 5 feet 6 inches would so slope as to be dangerous to the structure, and accordingly for manholes of less than that depth a dome shape is recommended.

It is desirable to cover manholes, both inside and outside, with a half-inch plastering of cement and sand in the proportion of one to one, so as to keep them absolutely water-tight. Step irons should always be fixed inside

manholes during their construction, when the depth exceeds 4 feet. The flooring of manholes should be made of cement concrete, having half-round channels formed in it, at the same gradient as the pipe, and with vertical sides of the same height as the pipe, such flooring and channels being finished off with a rendering of cement plaster. It is desirable in all manholes to place an indicator stone, with the number cut into it, near the top and under the cast iron frame. In a dome shaped manhole, it is not possible to place a stone under the frame so as to be visible, and it should therefore be placed in the floor as shewn in Plate 4. Around the mouth of the manhole, a fillet of cement and sand (1 to 1) should be placed for the reception of the cast iron frame, which should be so bedded on the masonry of the manhole that the top may be slightly above the original surface of the road, this level being designed to prevent the entrance into the manhole of storm-water.

Plate 5 shews two patterns of manhole covers and frames in use in the Bombay Sewerage Works. Both are good types, but that shewn in Fig. 2 is the newer and probably the better. The weight of frame and cover should not be less than 6½ cwt. It will be noticed that the cover fits into a slot in the frame, which ordinarily is soon filled with sand from the road surface, and becomes not only a water-tight but a fairly air-tight joint.

It is important, in districts which are liable to be flooded and which are drained on the separate system, that the manhole covers on the sewers should be water-tight. The type of cover shewn in Fig. 2 was recently experimented upon by constructing a water-tight wall round the frame and filling up the space with 12 inches of water, the cover thus forming the bottom of a cylindrical vessel; and it was found that with ordinary road detritus filling up the space between the cover and the frame, the whole was to all intents and purposes water-tight.

In cases where branch pipe sewers enter the manholes on main pipe sewers at a higher level than the main sewer, a drop pipe should be used as shewn in Fig. 21. As will be seen, the branch pipe sewer is brought down at an angle and finished with a bend discharging into the manhole at the main pipe sewer level, while an overflow and inspection pipe is provided by continuing the branch sewer pipe straight into the manhole and closing it with a metal flap valve. This arrangement avoids the splashing of sewage in a manhole—a proceeding conducive to the generation of sewer gas.

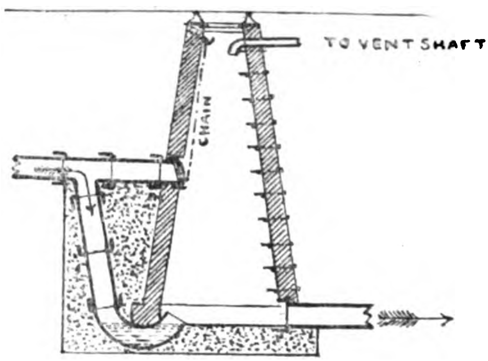


FIG. 21.

Flushing Tanks.—The provision of flushing tanks is very desirable in all sewerage schemes. The number and size of these tanks must depend to some extent on the gradients of pipe sewers and the class of sewage, but in general it is advisable to fix one at the head of each section. Plate 6 shews the type of flushing tank commonly in use in the Bombay sewerage system. The tank is constructed of brickwork in cement or hydraulic mortar and rendered with a half-inch coating of cement and sand (1 to 1), covered with stone slabs 6 inches in thickness, with the manhole frame and cover of the type before described fixed over the siphon. They are usually constructed to

contain from 100 to 600 gallons, according to the length and diameter of the sewer they flush. The flushing siphon is fixed in a chamber in the centre of the tank, the floor sloping both ways towards it. The lower end of the siphon dips into the water in the chamber and forms a trap. The water rises on the inside of the tank until it reaches the lip or adjutage, and, dropping over, expels a quantity of air, which continues until a partial vacuum is formed and siphonic action is set up, when the whole of the contents of the flushing tank is discharged. Each tank is fitted with a tell-tale, connected to a float, which registers each flush. The water-supply pipe should be provided with a reserve ball-valve.

The connection between a flushing tank and a manhole should be constructed in the manner shewn in Plate 7. A 6-inch cast iron discharge pipe from the flushing tank is built into the wall of the manhole and carried down by means of a bend so as to terminate two inches below the top of the channel of the manhole. This bend is fixed to the wall by means of a wrought iron strap, the details of which are given in the Plate. The floor of the manhole is inverted so as to carry the whole flush directly towards the outlet sewer.

Flushing Disks.—Messrs. Mather and Platt have recently introduced a flushing disk, which effects the holding up and discharging of sewage automatically and may very likely obviate the necessity of a permanent staff.

As an alternative to the disk valve, the flap valve shewn in Fig. 1 on Plate 8 is often used. It is fixed on the inlet sewer of a manhole and provided with a chain for opening and a strut for keeping the surfaces water-tight when closed. The flap is made of metal hung on hinges set with lead or cement in a stoneware block which is built into the brickwork of the manhole. A ring should be

provided on the chain to fasten on to a hook just below the manhole cover, so that the flap can be kept wide open when not in use.

Flushing Doors.—Flushing doors, similar to tidal flaps as described in the catalogues of various manufacturers, are an undoubted aid to flushing large sewers, as by these means a great quantity of pure water, which would otherwise be necessary, is dispensed with. Broadly speaking, a flushing door is a hinged iron flap placed in a manhole on the inlet side of the sewer. This can be securely closed, when required, so as to head up the sewage on the upper length of the sewer to any required extent. On opening the door, which should be done as rapidly as possible, the whole of the pent up sewage rushes forward at a greatly increased velocity to that which would be obtained in the ordinary way, scouring before it solids and other matter, which would otherwise tend to form a deposit on the invert of the sewer.

Large flushing doors, such as are used on the main ovoid sewers in Bombay, are provided with a hinged strut to keep them securely in their place when closed, and to this strut is attached a chain, by means of which the door can be raised to an horizontal position when required.

A reference to Plate 9 will shew the door in its lowest position and the hinged strut preventing it from opening. To release the door a chain is provided which is fixed to the ring (A) on the strut. In the larger sized doors, this is connected in a small chamber immediately below road level to a winding apparatus or to the lifting gear, as it is found impracticable to lift these doors by a direct pull. The joint (B) on the strut, being lifted, takes the position shewn by the dotted lines, and easily drops back into its proper place on the chain being released. These flushing doors have been found most useful in Bombay, where the accu-

mulation of silt in the sewers is considerable. The following observations shew the result of one average flush:—

Size of Sewer 2'-6"×3'-9".	Depth of Silt before Flushing.	Depth of Silt after Flushing.	Difference in depth of Silt.	
			Increase.	Decrease.
	Ft. In.	Ft. In.	In.	In.
Manhole 5	1—11	1— 8½	...	2½
Manhole 4	2— 0	2— 2	2	...
Manhole 3	1— 9	1— 9	...	...
Manhole 2	1— 9	1— 7	...	2
Manhole 1	2— 0	1— 7½	...	4½
Here Flushing Door.				
Manhole 1	2— 2½	1—10	...	4½
Manhole 2	1—10	1— 9	...	1
Manhole 3	1— 9	1—10½	1½	...
Manhole 4	1— 4	1— 6	2	...
Manhole 5	1— 7	1—11	4	...

From these observations it will be seen that above the flushing door 2½ inches of silt have been moved forward from No. 5 to No. 4 manhole, all manholes being 200 feet apart. In manhole No. 3, there is no difference after the flushing. In manholes 2 and 1, 2 inches and 4½ inches, respectively, have been moved forward. Below the flushing door, manholes 1 and 2 shew a decrease of 4½ inches and 1 inch of silt, while 3, 4, and 5 shew an increase of 1½, 2, and 4 inches. These results are satisfactory for one flush, and particularly when the distance between the manholes

and the area of the sewer is considered. By continuing the flushes, great good can be done in the way of cleansing the sewer. A somewhat similar method of flushing can also be used for pipe sewers, but the valve, which is preferably of a disk type, is in this case placed on the outlet from the manhole, and an overflow from the manhole (about 3 feet above the invert) is usually provided, discharging into the outlet sewer. The object of this overflow is to guard against the risk of the door being closed and accidentally forgotten, with the result that the sewage would force its way out of the lowest manhole cover. These small valves are inexpensive and undoubtedly useful, and might advantageously be placed a short distance from the head of branch sewers, simply leaving a sufficient length of sewer between the valve and the head manhole in which to store up enough sewage to create a satisfactory flush. In good gradients, these valves should be built into the manholes at intervals of 1,000 feet, but if the gradient is flat, then they should be placed at intervals of 500 feet.

It must be borne in mind, when considering the adoption of appliances of this kind, that an efficient and separate permanent staff is necessary to work them.

Catchpits.—These have been found necessary in the Bombay sewerage system, both for ovoid and pipe sewers, and are recommended for general use in India. The principal reason for their adoption is on account of the large amount of mineral matter, in the shape of sand, ashes, and road detritus, which, as before stated, finds its way into the sewers through the branch drains from every point. The catchpits as constructed in Bombay are shewn in Plates 10 and 11. They have successfully stood the test of time, and year by year their number is being increased as the sewerage system is extended. In the districts sewered on the Shone System of drainage, they are not required, because there it has been possible to adopt steeper gradients and

thus to decrease the possibility of the deposit of solid matter. The construction of catchpits on ovoid sewers should be wholly in cement brickwork or masonry. They should be fitted at both ends with penstocks, as shewn in Plate 10. and should slope towards the centre so as to facilitate cleansing. Each catchpit must be constructed with a cast iron by-pass, which is put into use only during the time of the cleaning of the main chamber. With catchpits on pipe sewers (Plate 11), the by-pass is done away with by having two chambers, both of which are ordinarily brought into use, except when the catchpit is being cleaned. Instead of a penstock, these catchpits are fitted with sluice valves, their size being governed by the size of the respective pipe sewers. Care should be taken in cleaning out these catchpits, for, when the silt is disturbed, they are apt to dangerously fill up with gas. There is no question as to the utility of these catchpits, at any rate in Bombay, as both small and large regularly fill with silt and require to be cleaned out at least once a month, and any scheme for the disposal of sewage with similar characteristics to that of Bombay would not be complete without such catchpits.

Ventilation.—One of the most important questions connected with sewerage schemes, and one that has exercised the minds of Sanitary Engineers for many years, is the efficient ventilation of sewers. It is not alone sufficient to merely ventilate a sewer and keep it reasonably free of poisonous gases, but it is imperative that the ventilation should be so carried out as to cause neither nuisance nor injury to the public, which can only be avoided by great care and judgment.

Sewer gas has been described in Moore's *Sanitary Engineering* as a "Fetid Organic Vapour"—a very apt description of it. Chemical analysis of the air in sewers shews it to generally consist of marsh gas (CH_4), Carbon Dioxide (CO_2), Ammonia (NH_2), Nitrogen (N), greater

or less quantities of Sulphuretted Hydrogen (H_2S) according to temperature, and Carburetted Hydrogen (C_2H_4).

Carbon Dioxide, or choke damp as it is also called, is the result of decomposition, and when inhaled in any quantity causes instantaneous prostration, often followed by death.

The presence of Nitrogen in sewers is due to the denitrifying of the organic matter in the sewage, which is the first stage of the bacterial work. Carburetted Hydrogen in sewers is often due to the leakage of gas pipes, but more often in this country to the decomposition of vegetable matter. It has a faint smell, something like burnt hay. In the Bombay sewers a large quantity of this gas accumulates. It is very explosive when mixed with atmospheric air, and for this reason no naked lights should ever be used in sewers until after they have been fully tested as hereinafter described.

Marsh gas, which is analogous to Carburetted Hydrogen, is the result of decomposition of vegetable matter and burns easily with a blue flame when ignited.

Sulphuretted Hydrogen—a gas nearly always present in sewers—is also a product of putrefaction; it has a very offensive smell and is heavier than atmospheric air; it is one of the most poisonous of all gases and has been responsible for the deaths of numerous workmen in sewers from time to time; it mixes freely with fresh air and becomes then comparatively harmless.

The ammonia present in sewer air is the result of bacterial action.

The mean temperature of the sewage in Bombay is about 76·5°, while the mean temperature of the air as registered at the Meteorological Observatory, Colaba, on the average of the observations of 56 years, is 79·60°. It is

obvious that at a temperature of 76·5° in the sewers, putrefaction and therefore the discharge of foul gases from the sewers will be great, and the fact that the temperature of the air is greater than that of the sewers is not in favour of successful ventilation.

Fresh sewage, however offensive it may be, is virtually harmless, but in its transit through sewers it becomes progressively noxious and dangerous.

Barometric changes effect the amount of foul air present in sewers. The lowering of the barometric pressure leads to the escape of gases in the sewage and favours decomposition and putrefaction, while an increase of barometric pressure enables the sewer air to carry a larger amount of vapour and therefore for the sewage to retain a larger amount of these gases, which are due to decomposition.

Increase of temperature of the liquid tends to expand the air held in the sewage, and consequently a quantity of the offensive gases is driven off under some pressure.

Temperature and barometric pressure are therefore very potent agents in connection with ventilation.

Steam hot water, and waste chemical products are all active agents in setting up decomposition in sewers and thereby freeing gas. Soda water manufacturers are especially culprits in this way, and the discharge into a sewer of waste water from a sodawater manufactory highly charged with carbonic acid gas has in Bombay prevented any access to the sewer in the immediate neighbourhood for days together.

Experiments made by the late Mr. Santo Crimp tend to shew that the direction and force of wind are great factors in ventilation, and he has stated that ordinary ventilating shafts often act as inlets or outlets according to the condition of wind for the time being.

That sewer gas has the power of predisposing the human body to disease is, no doubt, true, though there is no direct evidence to shew that it is the immediate cause of zymotic disease, but it is quite conceivable that it is an indirect one. On the other hand, it is a curious fact that the health of employés at Sewage Pumping Stations compares very favourably with that of people living elsewhere, and this is borne out in Bombay. New-comers, however, often suffer in divers ways, which suggests that the poisons—if poisons they be—which surround such stations are such as people can soon become immune to.

Some years ago, Mr. J. Parry Laws, of the London County Council, made some interesting investigations into the air in sewers, and proved that the micro-organisms found in sewer air were related to those in the external air; that they bore no relation to those in the sewage itself; and that, however full the sewage might be of disease germs, they would not pass into the air of the sewer, except possibly under conditions of great splashing. But in a later report he says that "although one is led almost irresistibly to the conclusion that the organisms found in the sewer air do not probably constitute any source of danger, it is impossible to ignore the evidence, though it be only circumstantial, that sewer air has had causal relation to zymotic diseases."

Dr. Louis Parkes, M.D., D.Ph., in the *Journal of the Royal Sanitary Institution* of April, 1895, is inclined to rather dissent from the opinions of Mr. Parry Laws, for he says that "it is clearly impossible that Mr. Laws' experiments could take account of all the varied conditions to which sewage may be subject in sewers. We know that at times steam, and large quantities of waste water at a high temperature may be injected into sewers from manufactories. Various chemical waste products also, acid or alkaline, occasionally find their way into sewers, and may then set up chemical decomposition in the sewage, and

tributary sewers frequently discharge their contents into main sewers so as to cause much splashing and agitation of the sewage. The local effects produced by these various conditions—and by others which will suggest themselves to the minds of those familiar with sewers—must be investigated at length before it is possible to assert that at no times and on no occasions are micro-organisms characteristic of sewage to be found in the air of sewers."

Many other notable Chemists and Medical Scientists have claimed that sewer air is incapable of disseminating the germs of disease; but it is almost certain that persons living in houses to which sewer air has access are more liable to zymotic diseases than those who live in a pure atmosphere. It is therefore of the utmost importance to carefully provide vent shafts for sewers and to ventilate house connections.

The term "ventilation" is usually employed to mean both the venting and the ventilation of sewers, *i.e.*, the letting of air out of and into the sewers; but the two terms should be differentiated as each refers to distinct operations. Sewers should be vented and house drains ventilated.

For this reason all manholes on sewers should be made air-tight and the vent shafts, as they naturally do, may be allowed to act as inlets and outlets alternately, in accordance with the meteorological conditions prevailing at the time, and as the depth of liquid in the sewer for the time being falls and rises.

Sewers laid at sharp gradients require more care in venting than those on flat gradients, because the gas naturally finds its way to the highest point of the sewerage system, sewer gas being generally lighter than atmospheric air. This, however, may not always be the case, as with

quick velocities the gas is sometimes carried along with the sewage.

Vent shafts should be as few as possible consistent with safety, the number being governed by the varying flow of sewage and the size of the sewers. Care should be taken to provide sufficient to prevent the pressure of the gas forcing the traps on the house connections, and they should not be less than 6 inches in diameter. The distance between vent shaft and vent shaft should, as a general rule, not exceed 400 feet. This distance has been found in Bombay to be satisfactory, provided that all house connections are properly protected by an intercepting sewer trap and its accompanying vent-pipe, and no special conditions prevail, such as the discharge of hot water or chemicals into the sewer. Under the latter conditions, the shafts should be as close together as circumstances may require.

The selection of the positions for vent shafts require careful consideration, and no hard and fast rule can be laid down in regard to them. They should, however, in all cases be as far removed from dwellings as possible; but if the local circumstances oblige their erection near dwellings, they should be carried up well above the roof of the highest house within a radius of 200 feet. Sewer gas will travel long distances in the direction of the prevailing wind, and in a city like Bombay, where houses are, for the most part, open night and day, the greatest care should be exercised in fixing vent shafts. These shafts, when fixed against houses, are for the most part made of iron, which, being a good conductor of heat, has the effect of creating a draught from the sewer. Therefore, if possible, a vent shaft should be fixed where the sun can shine on it for as many hours as possible.

The greatest care should be taken to see that all the joints of a vent shaft are most carefully made, so as to prevent leaks.

The usefulness of vent shafts depends on the difference of the pressures of air at the outlet and the inlet of the shaft, less the loss caused by frictional resistance.

In designing a vent shaft, it should always be remembered that the frictional resistance of the shaft modifies the current, the amount being in direct proportion to the length and inversely to the diameter or area of the shaft. Vent-shafts should, therefore, err on the side of being too large rather than too small, and should be of the same size from top to bottom. The nearer the sectional area of the vent shaft is to that of the average air space of the sewer it vents, the more efficient will it be.

In any system of sewer ventilation, simplicity and independence of mechanical aid are desirable. Natural ventilation should be made use of as far as possible, and gases on leaving the outlet of a vent shaft should be exposed to as much dilution with fresh air as possible.

It must always be kept in view that just as much fresh air as is admitted into the sewers must leave those sewers again as foul air.

The question of sewer ventilation is a very difficult one, and the last word has not been spoken in regard to it.

Some authorities now hold that sewer air has a greater density than atmospheric air, and does not rise as is generally believed but is forced out of the sewers by the rise of the sewage or by the formation and pressure of the putrefactive gases in the sewer.

Some years ago, in a section of the Bombay Sewerage System, it was decided to try surface manhole ventilators fitted with charcoal trays—a system which has been much used in England. Charcoal, to be at all effective as a disinfectant or a deodorant, must remain in a dry state, and it is manifest, therefore, that in Bombay, with its humid atmosphere, it would not be successful. As a matter of

fact, the manhole perforated covers in the dry weather allowed a quantity of sand and rubbish to enter and mix with the charcoal, completely filling the interstices and rendering it useless, and in the monsoon they admitted a quantity of rain water into the sewers with washings from the streets.

Plate 12 gives a drawing of an ordinary metal vent shaft as used in Bombay. It is rectangular in section and is 7½ inches by 4 inches. A masonry shaft, or sometimes an iron column, is used in places where there is no building to which a metal shaft can be fixed.

Plate 12 gives a drawing of an ordinary metal vent shaft, which has answered admirably in Bombay and other places. It can with safety be erected to a height of 60 feet without iron stays ; and, being of cast iron, it is constructed in several pieces.

The practice of leaving openings or grids in manhole covers for ventilating purposes has found many supporters, and even to-day some Sanitary Engineers consider it a suitable means of ventilation: but Engineers who have had much experience in the matter of ventilation, know that the surface grid ventilation must under all conditions be a fruitful source of nuisance. In some schemes with which the Author was connected in England, the force of public opinion was so great that the surface grids which were fixed when the sewerage was carried out had all to be closed within a short time. It is quite certain that with the high temperature that prevails in the East, no such class of ventilation would be tolerated for a moment. The greatest care has to be exercised in Bombay to keep manholes absolutely air-tight, and a special form of manhole cover, referred to elsewhere, is used for this purpose.

There are various kinds of mechanical ventilation, a slight description of some examples of which may be useful.

The extraction and destruction of sewer air by a gas jet is a form of ventilation which has been used in many places in the British Isles. One of the principal forms of this is known as J. E. Webb's Patent Sewer Gas Extractor and Destructor Lamp. By this system it is claimed that the sewer air is drawn out of the sewers and subjected to a temperature of 600° F., and that all disease germs and noxious gases are absolutely destroyed. It is stated that one lamp costing some £20 will effectively ventilate one mile of an average sized sewer, the extracting capacity being 2,500 cubic feet of sewer air per hour. These lamps, which are in the form of ordinary street lamps, it is said, can be used equally well with incandescent burners. The economy of using this system is obviously dependent on the price of gas, and it is possible that in the East, where only a few towns have the luxury of gas, the cost of the commodity will be too great to allow of it being used economically.

The Reeve System of sewer ventilation aims at producing the oxidation of the sewer air by artificial means. The sewer gases are destroyed in manholes by a special chemical apparatus, whence it is obvious that the necessity for vent shafts is done away with.

Plate No. 14 is a drawing of the apparatus necessary to this system, and the following is the description of it as given by the makers:—

By means of the water supply, the Reevozone, with which the large container (A) is charged, is automatically liquefied and delivered continuously in any required quantity on to the mixing disk (B). Here it is mixed with the necessary quantity of acid, supplied also continuously, from the small container (C). Nascent oxygen—a powerfully oxidising gas—is thus generated, and also a strong permanganic liquid is produced, which flows from the mixing disk to the cooling cylinders (D) placed underneath

the mixer. The strong permanganic liquid, as it trickles on to and down the sides of the cooling cylinders, is caught and beaten up into a very fine permanganic spray or mist, by the action of the sprayer (E), which is shewn just over the cooling cylinders in the Plate. With the strongly oxidising gas and mist the ventilation shaft is kept supplied. Thus, when the current is inwards naturally, atmospheric air entering by the grating goes down into the sewer charged with nascent oxygen and permanganic mist, both of which add greatly to its power to oxidise organic impurity; while, on the contrary, when the pressure inside the sewer forces the sewer air outwards, the latter not only escapes freely by the grating but in an innocuous condition, being completely purified by its passage through the permanganic mist and nascent oxygen. By the action of the Reeve apparatus, currents of atmospheric oxygen are induced by the gratings even under those meteorological conditions, when, in accordance with the laws governing the action of gases, sewer ventilation which is wholly dependent on natural causes must become totally inadequate and even sometimes fail altogether. The permanganic mist, mixing with the sewage and acting as an antiseptic to such extent at least as it may not have been exhausted on the sewer air, lessens the evolution of gas from the sewage. The perfect ventilation which the Reeve System secures also acts as a preventive of the evolution of gas from sewage, because putrefaction is less rapid in pure than in foul air. The water supply enters the apparatus by the double locking siphon water-seal (F), which thoroughly protects the water main from any back pressure. This arrangement meets all the requirements of the Water Companies and is an important feature in the system.

A necessary element in the satisfactory working of the system is a water supply under pressure. It is stated that it can be worked even if the pressure drops down to 5 lbs. per square inch, but usually a pressure from 15 to 30 lbs.

is desirable. The cost, including water pipe connections, for installing the apparatus in a manhole would be from £10 to £35, and the annual cost of the chemicals about £20.

The system is said to have been installed with satisfactory results at several places in the British Isles, notably at Eastbourne and Edinburgh.

When Shone's Hydro-Pneumatic System is used, the ventilation of the sewers in each sub-district is carried out by a number of inlet shafts and one outlet shaft, the latter being used for the double purpose of disposing of the exhaust air after use in the ejector and of ventilating the gravitating sewers. The process, which has been partly described in an earlier Chapter *vide* Plate 2 and pages 15-16. is that the air—which enters the ejector at a pressure higher than that of the atmosphere and leaves it after ejecting the sewage at about the same pressure—is used to create a draught in the outlet shafts: these being connected with the pipe sewers, draw the foul air from them, its place being supplied by fresh air entering the sewers through the small inlet shafts erected at the head of each gravitating sewer. The experience gained in Bombay shews this system to be very successful, but the drawback—and it is a serious one—is that the sewer air is discharged into the atmosphere in large puffs, and often, before it can be sufficiently diluted with fresh air and rendered harmless, it is borne by the prevailing wind into houses within 200 feet in the direction of the wind. It is, of course, impossible in a city where huge buildings of five, six, and seven stories exist to construct iron columns of such a height as to be out of all danger, and therefore some means of destroying the gas before it leaves the shaft is a great desideratum.

Recently, Mr. Shone has patented another system of ventilation, which he calls the "20th Century System of Ventilation," and it will not be out of place here to give a

brief description of it. The general principle on which the system is based is the creation of a partial vacuum in sewers and the admission of controlled volumes of atmospheric air through patent valves on the house connections, all other inlets to the sewers being either stopped or trapped. The partial vacuum, which is equal to about half an inch of water, is produced by means of an exhaustor fan driven by some motive power such as steam, electricity, or compressed air. The air removed from the sections of sewers thus dealt with is discharged through one vent shaft fixed in connection with the fan.

It is evident that if the proportion of the atmospheric air is very large as compared to sewer gas, the resultant mixture can be safely discharged into the atmosphere without causing any nuisance.

For this scheme to be successful, it must have the sewers or the system of sewers absolutely air-tight, and any leaky joint or manhole cover would seriously militate against the successful working of the whole system.

Plate No. 15 shews the system in detail and the position of the fan.

The system has been installed at the village of Darley Abbey, at Leicester and at Manchester.

At Darley Abbey the system is a complete one, that is to say, the whole of the sewers of the village are ventilated by Mr. Shone's system. The present number of houses in Darley Abbey is 200 and the estimated population is from 1,000 to 1,200. The water supply is equal to 15 gallons per head, but the sewers are designed to take away double that quantity. A 15-inch Sirocco Fan, capable of making 1,500 revolutions and delivering 500 cubic feet of air per minute up the ventilating shaft, is fixed in a convenient position at the lowest part of the drainage system, so that the tendency of the air to move downwards in the direction of the flow

of sewage may co-operate slightly with the work of the fan. Mr. Shone considers that if a volume of fresh air, equal to 1/10th of a cubic foot per minute per inhabitant, is sucked into the system through the inlet valves, it will be able to dilute the gases of any sewage sufficiently to permit of their being discharged into the open air with impunity. The volume of air required to ventilate the sewerage system at Darley Abbey on the basis of 1/10th of a cubic foot per minute per inhabitant would only amount to 120 cubic feet; but looking to the fact that an allowance has to be made for leaky manholes, etc., the fan has been designed to deal with 500 cubic feet per minute. This has proved to be an ample allowance and the installation has been working satisfactorily for two years. Plate No. 16 is a drawing of a regulated air inlet plug, which is considered by the Author to be a satisfactory arrangement.

At Manchester the trial installation has been working for a year and the authorities are said to be quite satisfied with its efficiency. As regards Leicester, the Borough Engineer, Mr. John Mawbey, M.Inst.C.E., has published an account of his experience of the working of the system at that place. He states that the area under the influence of the system is 2½ acres and comprises portions of the more modern part of the borough. The total length of the sewers ventilated is about 900 feet. The sewers are laid at an average depth of 10 feet, being principally 12 inches in diameter, discharging into a 3 feet by 2 feet ovoid sewer. The house drains connected with these sewers comprise a length of about 1,750 feet, being mostly 6 inches in diameter.

There are no intercepting traps on the pipe drains. Of the 80 houses connected to the system, 27 are provided with ordinary ventilating pipes. At the lower end of the system a chamber is provided containing a 15-inch Sirocco Fan, driven by an electro-motor working at 700 revolutions

per minute. One end of the chamber containing the fan is connected to a circular steel ventilating shaft, 40 feet high. The fan is connected to this shaft by a zinc pipe, tapering in size from 7 inches square to 9 inches in diameter. The working expenses of the system are practically confined to the cost of the electric current consumed in driving the motor. The repairs and maintenance are very small. The first experiment extended over a period of five consecutive days. The velocity of the air discharged through the extraction shaft and of the air entering at each inlet was registered by an anemometer. Once during each of the five days a 10 minutes' test was taken at each of the 27 inlets. The average result of these tests was that 275·10 cubic feet of air per minute were extracted through the extraction shaft, at an average velocity of 1,266 feet per minute, and a total of 31·17 cubic feet of air per minute was admitted to the 27 inlets on the private ventilating pipe at an average velocity of 29·3 feet per minute. The inlets in the private ventilating pipes varied in diameter from 5/16ths of an inch to one inch and the total area of the 27 inlet pipes was equal to 10·278 square inches.

There is a great discrepancy between the total volume entering the inlets and the volume leaving the extracting shaft, due doubtless to the fact that the volume of air entering these inlets was too small to be registered and also that some of the air is drawn in through the manhole and lamp hole covers.

In the second test that was made, the size of the extraction shaft was increased from 6 inches to 9 inches, with the result that a largely increased amount of air was extracted. The result of the experiment satisfied Mr. Mawbey that the system was both practical and efficient and one on which reliance could be placed throughout all seasons of the year.

Five sets of air analyses were made during the experiment, and they shewed that the external air contained on an average 3·55 parts of carbonic anhydride per 10,000 parts of air; that the air in the manholes at different parts of the system contained on an average 15·10 parts of carbonic anhydride; and that the air as discharged at the extraction shaft contained 13·14 parts.

As stated earlier, the last word in regard to ventilation has not yet been said. It is a fact which the Author considers should be kept well in mind by Sanitary Engineers, that any expensive system of mechanical ventilation is likely to add very seriously to the cost of a sewerage system, which often constitutes a severe burden not only on the rates but also on the rate payers. A considerable amount of the work is doubtless carried out at public expense; but some portion, and that by no means insignificant, falls on the house-owners themselves. Any kind of mechanical ventilation will, however, assuredly add more or less to the cost of the scheme. At present, even in the British Isles, where many experiments have been carried out in regard to ventilation, there is a great variety of opinion as to which is the most suitable scheme.

There are some Engineers who argue that sewers are better if not ventilated at all—a theory which finds corroboration in the curious circumstance that Bristol, where there is no ventilation of any kind, boasts of almost the lowest death rate in the United Kingdom. The Author has given much thought to the subject, and is of opinion that, so far as our present knowledge goes, the venting of sewers should be attained by means of vent shafts of suitable size placed at regular intervals, the manhole covers of the sewers being made practically air-tight.

Removal of Obstructions in Sewers.—In India, all sewers are very liable to obstruction and chokes. The

universal habit of cleansing cooking utensils with sand and the frequent use of broken tiles and road metal in latrines are the principal causes. In Bombay, the usual method of keeping the ovoid sewer clear of deposit or silt is to draw a shield or scraper through the sewer by means of a winch and chain. This shield or scraper is made of wood in two patterns, one with the bottom part cut off and the other with the top cut away about a third of the distance down: both are constructed of the same shape as the sewer, with wheels both at the bottom and the sides, and are of a size to leave about 1½ inch play on each side, to give greater facility in moving. The shield or scraper is dragged through the sewer from manhole to manhole, the sewage finding its way with increased velocity, either over or under the scraper, and thus softening the silt in front. The silt is pushed forward before the moving scraper into the nearest catchpit or goes on to the pumping station, where it is lifted with the sewage by the pumps. The scrapers are constructed so as to take to pieces, every part being bolted together when required for use. This is necessary, as the scrapers have to be put together in the sewers, and even then a specially large manhole is sometimes necessary to allow the larger part of the scraper being introduced into the sewer. The above method has been found to be the only means of moving the heavier particles of silt in the sewers. It has the disadvantage, however, of being destructive to the cement plastering of the sewer.

Where the silt is very hard, the scraper mounts on to the top of it instead of moving it forward, and this frequently happens where it is practically impossible to do any repairs. Plate 17 shews the apparatus in detail.

For pipe sewers usually a double disk, as shewn in Fig. 22, is used and dragged through them, the silt being removed by hand at the nearest manhole. This arrangement is probably as satisfactory a way of cleaning pipe sewers by hand as can be arranged, and has been in use in Bombay for some years. At one time an attempt was made to clean pipe sewers by placing a round metal and hollow ball in the sewer, nearly the same size as the sewer, and allowing the sewage to force the ball forward, but the attempt was not satisfactory, as the ball stuck hoplessly in the silt in the sewer and had to be dug out.

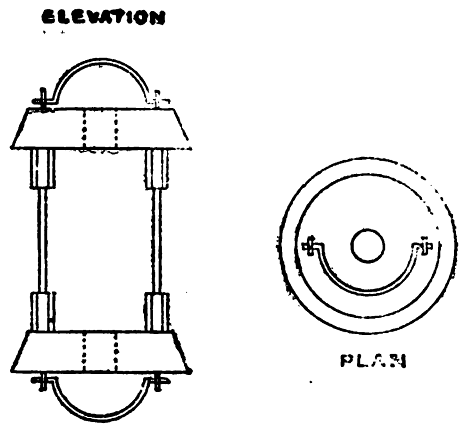


FIG. 22.

Rules to be Observed in Cleaning Sewers.—The following precautions should be taken when men are required to enter and work in sewers and drains:—

When only two men are engaged in opening a manhole, it should be securely fenced round before the cover is removed, and the fencing should not be removed until the cover has been replaced. This precaution should be very carefully observed in order to prevent accidents to traffic, the liability for which may be brought home to the body responsible and heavy damages claimed.

If there are more than two men engaged, the cover may be removed before the fence is erected, or the fence removed before the cover is replaced, provided that one man—not

below the rank of a Foreman—be stationed at the open manhole, not to leave it so long as it is open. An open manhole, whether fenced or unfenced, should never be left without some one on guard to prevent accidents, and the guard should not leave it so long as it remains open.

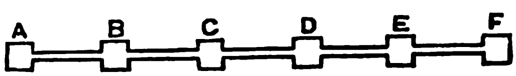
Workmen should on no account enter a manhole, except under the immediate orders and in the presence of the Chief Inspector, Inspector, or Sub-Inspector, or of a muccadum who has satisfied the Chief Inspector that he understands (and is competent and may be trusted to apply) the tests prescribed in these rules for determining the quality of air in a sewer.

Workmen should on no account go up a sewer beyond the manhole, except under the orders and in the presence of the Chief Inspector, Inspector, or Sub-Inspector.

The first duty of the person in charge of men entering a sewer, drain, or manhole is to see that he has supplied himself with the following appliances:—(*a*) chemical test papers; (*b*) lights; (*c*) bamboos; (*d*) windsails; (*e*) strong ropes and cords; (*f*) diver's air pump (or blast-fan); (*g*) air tubing; and (*h*) picks, *phaoras* (native shovels), pails, gamels, and whatever implements may be required for the actual work.

Not less than six manholes—at least, two in each direction, above and below—should be open when it is intended to enter either a sewer or a manhole.

The following sketch of a sewer with a series of six manholes in succession (A, B, C, D, E, & F) illustrates the system to be adopted:—



All the six manholes should be open for free ventilation for an hour or more before a man enters a sewer or a

manhole. At B and also at E a windsail should be erected with the flaps kept extended towards the direction from which the wind blows. The work should commence either at C and proceed towards D or at D and proceed towards C. Assuming that the work begins at C, then a diver's air pump or blast-fan, with a flexible air tube, should be set up at C and kept constantly at work. Before a man enters a manhole, the air pump or fan must be worked for five minutes, and before going into a sewer beyond the manhole for ten minutes.

A competent man, according to the instructions contained in the above rules, should be placed in charge of the work, and he should satisfy himself by inspection at first and from time to time afterwards that the sewer is not dangerous to work in.

It should not be overlooked that although near a manhole the air may be pure, yet further within the sewer it may be fatal to life; and if a fatality occur, it is as well to remember that a charge of culpable negligence may be brought, and very rightly, against an officer who orders a man to work in a sewer in which proper precautionary measures have not been taken.

Before the following tests are applied, the silt deposit at the bottom of the manhole should be first thoroughly stirred up with a rod or bamboo so as to agitate and dissipate the noxious gases, which would otherwise be a serious source of danger when disturbed by the workmen's feet.

Chemical papers for testing the presence of sulphuretted hydrogen gas should always be used.

If a paper, after five minutes' exposure in the sewer, turns a deep brown or black, the sewer is dangerous to work in, and further ventilation should be allowed and the test repeated before entrance is permitted.

If the paper test is satisfactory, a light may next be let down into the sewer by means of a cord running over the end of a staff. The light should be a naked light, that is to say, if placed inside a lantern, the door of the lantern should be open. This being a test not only for choke damp but also for combustible gas or fire damp, no one should stand near to or over the manhole while the test is being applied. If the light burns unnaturally or goes out, the men should not descend.

Even if the tests have been made and found satisfactory, no man should go down with a naked light, but only with a Davey Safety Lamp; and one such lamp, if men are working in a covered part of the sewer, should always be kept 20 feet in advance of where the men are at work and they should be cautioned to observe that it burns properly. If it does not do so or goes out, the men should all return to the nearest manhole immediately and ascend to the surface.

No man should be allowed, on any pretext whatsoever, to be in a manhole or sewer with a naked light, and on no occasion should he smoke in the manhole or sewer or strike a match.

No man should enter a manhole when the sewage is above the crown of the arch of the sewer or the top of the pipe; but if it be absolutely necessary to do so, the greatest care should be taken to watch the sewage, and in the event of its falling to within 2 inches above the crown of the arch or top of the pipe, the men should immediately come up and not re-enter the manhole until fifteen minutes after the sewage has fallen below the crown and fresh tests of the condition of the sewer have been applied.

Each man should be fastened by a stout rope passing under his armpits and with a knot against his spine: the rope should be kept from slipping down to the lower part of the body by means of short pieces of cord passing

over the shoulders. The foremost man should have the end of the tube supplying fresh air from the fan always a little in advance of him, and should carry it himself if possible; but if the latter be not found practicable, another man should be employed to carry the air tube.

In any case, one man should always be stationed at the bottom of the manhole to give an alarm and render assistance if required.

The men should be cautioned that if they feel any difficulty of breathing (or feel unwell in any respect), they should not remain in the sewer but come up immediately.

No man should be allowed to remain in a sewer more than half an hour at a time.

At least three men should be stationed on the surface of the manhole from which work is being carried on.

When the work has been completed from C to half the distance between C and D, the work should be begun from D and proceeded with towards C, similar arrangements and conditions being observed.

These instructions for executing the work between C and D apply to carrying out the work between any other two manholes, the windsails, air pump, or fan and other appliances being moved as required.

If an accident occur, every person in the sewer should be brought to the surface as rapidly as possible, and whilst they are being so brought out, crowding around the manhole should be prevented, because a crowd would check the escape of foul air or the entrance of fresh air.

If any person brought out of the sewer is insensible and medical attendance cannot be immediately obtained, some of the following should be adopted:—(*a*) Loosen all clothes about the body; (*b*) dash water on the face, which should be turned towards the wind; (*c*) lay the man flat on his face with one of his arms under his forehead, and (*d*)

open his mouth, draw his tongue forward, and cleanse his mouth and nostrils with water, or (*e*) turn him on one side while supporting his head, and turn him back again on his face: if breathing does not commence, (*f*) turn him again gently on to one side and then on to his back; (*g*) raise his head and shoulders; (*h*) grasp both his arms just above his elbows and draw them gently but firmly upwards, and keep them in that position two seconds; (*i*) lower his arms and press them gently against his sides; and (*j*) continue to raise and lower his arms as described until breathing is restored or until the man is placed in charge of a doctor: if breathing be restored before the doctor arrive, (*k*) rub the man dry and wrap him in warm dry clothes; (*l*) do everything possible to restore warmth and circulation; and (*m*) as soon as the man can swallow, give him warm water or any kind of diluted spirits to drink.

CHAPTER III.

PUBLIC CONVENIENCES.

All Eastern towns of any size should be supplied with public conveniences in the shape of latrines and urinals, as otherwise road-side drains or odd corners would be made use of, and these in a tropical climate soon become offensive.

Generally, far too few conveniences are provided; and that this is the case even in Bombay is evident from the use made of those that do exist, it being not uncommon to see persons awaiting their turn outside latrines and urinals. There is no doubt also that these conveniences serve the double purpose of preventing the committal of nuisances in the streets and of educating the lower classes to the necessity for sanitation and to the desirability of decency. It is almost incredible, but none the less true, that a large number of the poorer classes still require positive assistance in such an apparently obvious matter as the correct direction to face when using privies. Two devices are commonly employed for this purpose: a small looking-glass fixed on the front wall of the latrine, about three feet from ground-level; or the mark of an outspread hand painted in red by means of a stencil. The vanity inherent in the very humblest human being makes certain that the glass will be faced with keen inquiry; while religion ensures, among Hindus at least, that the back will not be turned to the sign of the hand. The imprint of the open hand has long been regarded by both Hindus and Mahomedans as a sign of

plenty, and when placed on the wall of a building, it is supposed to invoke a blessing not only on such building itself but also on the inhabitants thereof. In consequence, many castes will not voluntarily turn their backs on so suspicious a sign.

The word "latrine" is used to describe a convenience on either a dry or a water-carriage system. For facilities in carriage, latrines are usually constructed of corrugated iron with an angular iron framing: but it is not a desirable form of construction, particularly up-country, where during the hot season the iron gets so heated as to be quite unusable. The construction with wooden frames and brick nogging, though slightly more expensive, is decidedly better.

Dry Pattern Latrines.—The following are the descriptions of a few dry pattern latrines, for use in connection with cess-pools or sewerage systems, which have been widely adopted in India.

One of the simplest is probably that shewn on Plate 18, and known as the "Horbury Pattern Privy." This is constructed of corrugated iron sheeting fixed to an angle iron framing; the squatting plates are of cast iron and the sewage receptacles are ordinary iron buckets, generally well-tarred or dammered and easily removed on opening the flap door at the back. The flooring of such privies should be cemented or paved.

Another latrine which has found favour is the Donaldson pattern, as shewn in Plate 19: these have been principally used in Bengal and Madras. It will be noticed from the design that the liquid—which is separated from the solids—is passed by means of a drain into a covered tank or reservoir, while the solids fall into a receptacle. The superstructure of the latrine is corrugated iron bolted to T and angle iron. All floors and surfaces are finished with Portland cement.

Plate 20 shews an ordinary type of privy much in use and constructed of wooden posts and brick masonry. In this privy the solid matter is retained in a cane basket about 15 inches in diameter and 12 inches high, the interstices of which allow fluids to pass out and flow over the cemented floor into a trap fixed on a pipe drain, which is connected to a cess-pool or a sewer according to circumstances. The cess-pool should be constructed underground, of brick masonry, plastered with cement, and of a capacity below the level of the inlet pipe, equivalent to three cubic feet for every seat of the privy. It is covered with a cast iron or wooden cover and is ventilated by means of a 3-inch cast iron pipe, fixed in a convenient position and finished with a T head.

A basket can hardly be called a satisfactory receptacle, as in no possible way can it be kept thoroughly sanitary. The division of the solid matter from the fluid in this way is most undesirable, because not only is the outside of the basket fouled, but also a large portion of the cemented space on which the basket is placed, and if this is not constantly flushed, it becomes a source of considerable nuisance; while flushing causes large quantities of water heavily charged with night-soil to pass into cess-pools or drains not intended for such fluid. This is a frequent source of great nuisance.

Plate 21 gives a drawing of a range of the Crawford System Latrines, so called because they were introduced by the Bombay Municipality when Mr. Arthur Crawford was the Municipal Commissioner. In this class of latrines the solid and the fluid matters are collected in one bucket, the contents of which are removed by hand daily or more often if necessary. This is more sanitary than the basket system, and provided the buckets are regularly and frequently emptied, there is little objection to this method. No connection from the latrine to a cess-pool or sewer is required, the whole of the excreta, both liquid and solid, being removed by hand.

Plate 22 shews a range of Improved Dry-system Latrines which are similar to the Crawford System, but differ in so far that the receptacles for the solid and fluid matter are covered with iron perforated covers.

In both the above latrines, the sloping shoot, which is usually constructed of wrought-iron, requires to be daily cleaned and brushed by the attendant in charge of the latrines. The shoots, as also the receptacles and their covers, should be well tarred or dammered from time to time. Tar is credited with considerable and lasting deodorising and antiseptic properties, and every application not only probably exerts these influences but covers up with an impervious skin any offensive matter that may have sometimes deprecated, there can be no doubt that, for the special purposes for which it is recommended, it at present stands without a rival. Both latrines can be economically constructed on a masonry or concrete foundation with a cement flooring, the superstructure being of light angle iron standards with sides and roof of corrugated or sheet iron.

The size of a range of dry pattern latrines, *i.e.*, the number of seats it is to contain, is best arrived at by determining the population likely to use the latrines per day and allowing one seat for every twenty adults.

A convenient way of constructing a range of latrines is to place them back to back, those for males being on the one side and those for females on the other, with a 4-foot paved gully between for the removal of the basket or buckets and for cleaning purposes.

Latrines on Water-Carriage System.—Where-ever possible, latrines on the water-carriage system are to be preferred to those on the dry-system. Many forms of this class of latrine have been tried in Bombay with varying success, and of late years very great improvements have

been made. It is only recently that manufacturers have constructed a porcelain or glazed stoneware pan of a shape agreeable to the natives of India. Previously cast iron was used, and sometimes stone or concrete. This cast iron pan was never very successful, for it was difficult to keep it clean, and as it could not possibly be made entirely smooth, it soon became coated with fœcal matter. The cast-iron pan is now practically obsolete, the porcelain or stoneware pan being largely used in both public and private water-carriage latrines in Bombay.

The compartments of a latrine are usually built 2 feet 6 inches by 3 feet—a size found to be sufficiently large. (In one town in India a latrine was built with much larger compartments and attained an altogether unexpected degree of popularity, it being used as residential quarters.)

Each compartment is usually provided with a three-gallon flushing-tank, fitted with a pull-off chain and a ball-cock; but it has been found that these chains were constantly being jerked off and stolen, and later a rod was substituted for the chain, but with no better success. Finally, automatic flush tanks were successfully substituted for these pull-off flushing tanks; but this class of flushing tank, unless carefully watched, is very wasteful as regards consumption of water. It should be carefully adjusted to discharge four times daily, or as many more times as circumstances may shew to be necessary. On the top of each range of compartments is placed a water-storage tank running the whole length of the latrine, fitted with a ball valve and containing about 500 gallons, so as to provide a storage of water for the latrines in case of an interrupted supply from the water main. This storage tank may not be necessary in all places or if a constant supply in the mains can be depended upon.

Plate 23 gives a drawing of the newest water-carriage system latrine now in use in Bombay. In this a porcelain

pan is substituted for the antiquated cast iron form, and the inside of each compartment is lined to a height of three feet with white glazed tiles. Each latrine is fitted with a three-gallon automatic flushing tank, fixed on brackets at such a height as to be out of reach of interference. The soil pan is flushed from the front and also by means of a flushing rim, which surrounds the top of the pan. Foot-rests are also provided in the proper positions for the users to squat on. The special trap used in the old pattern latrine is here done away with, and the contents of the pan are discharged through an ordinary trap direct into the pipe drain.

Brass is especially esteemed by the natives of India, and it is not uncommon in these latrines to find brass handles and other fittings stolen. For that reason all fittings should be preferably of iron and bolted to their places.

In connection with an installation of latrines, it is desirable to provide a few small seats in the enclosed space for children. A properly paved and drained washing place is also necessary, the water-supply pipe being fitted with an ordinary brass plug tap.

In public latrines on the above system, it is usual to fix the number of seats on the basis of one seat for every fifty adults who are likely to use the latrines per day.

Trough Pattern Latrines.—In some places it will be found that trough pattern latrines have advantages over those on the water-carriage system just described. They are more suitable when required to accommodate large numbers of people, and for that reason are especially adapted for Mills and Factories.

There is practically no limit to the number of persons who may make use of a trough latrine daily, and there are no fittings which can be in any way tampered with.

The structure can be made of corrugated iron or some such cheap material or masonry, latrines built of the latter material being naturally more lasting.

Plate 24 gives a drawing of a trough pattern latrine, which has given general satisfaction. In this latrine a depth of six inches of water always remains in the trough, which is generally constructed of a half 6-inch or 9-inch stoneware-pipe according to the number of seats. The trough is, automatically or at will, flushed from a 50-gallon flushing tank placed at its higher end. The form of the pan at its top is similar to that of the water-carriage latrine last described, with the lower half cut away, and is without any kind of trap. When this pattern of trough latrine was first tried, it was found that the users got splashed, and for this reason natives had a great objection to it. The trouble was, however, got over by hanging a small iron plate under the pan and just above the normal level of the water in the trough, so that, when the flushing tank discharged, this plate became completely covered and cleansed of any solid matter on it. This arrangement has been found satisfactory and has removed the original objection. These latrines are simple and economical and, for public use among the poor and more uneducated classes, are perhaps the best.

Plate No. 25 shews an improved Trough Pattern Latrine. Each compartment is provided with a glazed earthenware pan, the outlet of which is connected by a glazed stoneware pipe to the trough. The invert of the trough may be constructed of a four-inch glazed channel pipe, for any number of compartments up to ten: above that number, a six-inch channel pipe should be used.

The invert of the trough should be level with a weir at the outlet and so adjusted as to retain 2½ inches of water in the trough. Care should be taken to have the invert of the outlet pipe from the pans level with the water

line in the trough. The trough is flushed by means of an automatic flushing cistern of the capacity of five gallons for any number of pans up to five; and above that number the capacity of the flushing cistern should be increased at the rate of one gallon per each additional pan.

The working of this latrine is much assisted by the flow from a bathing platform or by a sink being drained into and through the trough. In some cases, such a flow has been found to be sufficient to efficiently flush the trough. Several of these latrines are in use in various mills in Bombay and have so far proved quite sanitary.

The Author considers that many of the objections to a trough latrine have been overcome by this improved pattern.

Urinals.—As in latrines, so in urinals, great strides have been made in Bombay towards securing greater sanitary efficiency. One of the earliest urinals constructed in Bombay, and one that was in use for many years, is shewn in Plate 26. This urinal is for the most part constructed of iron and may be of any length and of various shapes. The compartments may be divided by wrought-iron partitions five feet in height. The pan of the urinal, which can be continuous from end to end, holds water which at the greatest depth is 6 inches. The users squat, as is the distinctive custom in India, on slightly raised iron-steps, and the urinal is flushed from an automatic over-head tank of a sufficient capacity at each flush to displace the whole of the standing water in the urinal.

Plate 27 shews a circular urinal on this system.

This type of urinal was never quite satisfactory, as, being almost entirely constructed of iron, it rusted rapidly; while it was not possible to keep it in a sanitary condition, as it lent itself to misuse as a latrine, for which it was manifestly not suitable. These urinals were almost the first public urinals constructed in Bombay, but they have

been nearly all replaced with the new pattern hereinafter referred to.

The newest form of urinal used in Bombay is shewn in Plate 28. It is a trough pattern and was designed by the Author in conjunction with Colonel T. S. Weir, I.M.S., late Health Officer to the Bombay Corporation, and is known as the "Combined Constant Flushing Urinal." The trough is of white porcelain, and the front is lined with glazed tiles to a height of 3 feet 6 inches or as far as the copper flushing pipe. The urinal is flushed continuously from a tank placed on the top of the structure and extending nearly its whole length. The size of the water-supply tank may be calculated on the basis of 50 gallons per division per day, so that, if the urinal has four divisions, the tank should hold 200 gallons. All parts of the trough and the front wall continually receive a small stream of water. The partition walls, which are marble slabs, are 2 feet 3 inches apart and 6 feet in height. The contents of the urinal discharge through a trap placed at the lower end and connected with the sewer. The name "Combined" was given to this urinal, because of the great advantage of its being able to be used sanitarily either in a standing or squatting position, and is thus suitable for all races. From time to time, the trough and the front require to be cleaned with a dilute solution of sulphuric acid in order to remove stains, which after a while discolour the glazed surfaces. The urinal has been a success and is undoubtedly the most sanitary for general purposes yet constructed in Bombay. Many have been built in the City in various positions, and Plate 29 shews one placed in the angle of a wall.

The cost of such a urinal is somewhat greater than that of the old cast iron pattern, but being a combined urinal, its advantages greatly overweigh the slight extra expense.

8

The use of continuous flushing for urinals has of late, to a large extent, been discontinued in England and periodic flushing substituted, because of the large amount of water used by the former ; but in a country like India, it is not advisable to economise water in a public convenience.

Plate 30 gives a useful design for an underground public convenience after the pattern used in London. The depth of the structure underground, from the surface of the road to the floor, is 7 feet, it being also 1 foot 6 inches above the surface of the ground; but the underground depth can, if necessary, be greater, the level of the connecting sewer governing that point. The place is lighted by means of Hayward's Patent Glass Lights inserted in the roof. Steps are provided on one side for the entrance to and the exit from the structure. It contains two separate water-closets, one for Europeans and the other for Natives, and two hand-washing basins. Conveniently situated and next to the native water-closet is a washing-place fitted with a stand-pipe for obtaining water for ablutionary purposes. There are also provided six Combined Constant Flushing Urinals, three on each side, and a small ornamental drinking fountain is placed at the bottom of the stairs leading to and from the structure. The whole installation is complete both for Europeans and Natives, and should prove to be a very useful convenience in the business part of a large town. For the use of a water-closet a small charge could be levied to meet the wages of the attendant in charge. Some artificial method of ventilation is almost indispensable in an Indian city for such a structure, and possibly the simplest would be by means of shafts topped with revolving cowls.

Plate 31 shews a useful and complete above-ground installation of public latrines, urinals, and washing places with a well-paved and drained enclosure. This and similar installations have been constructed and are in use in

Bombay, and have all the necessary conveniences for both sexes. A partition divides the latrine into two parts for the different sexes, each side being supplied with its own washing-place. The latrines themselves are on the newest pattern as shewn in Plate 23.

Such an expensive class of latrine for use in all parts of the city is not recommended. In crowded and poor districts a trough pattern would be preferable, both on account of its lesser cost and because of its greater sanitariness under careless usage.

Discretion is necessary in deciding on a pattern and size of public latrines, as certain classes of people will not use them under any circumstances and certain classes are not yet sufficiently educated to use them properly.

Night-soil Depots.—In no Indian city has the introduction of water-closets in private houses yet become universal or even common. In Bombay, in by far the larger portion of the city, night-soil is removed by hand, either in tarred baskets or in carts into which the baskets are emptied, and taken to the nearest night-soil depot and discharged into a sewer.

Plate 32 shews a complete night-soil depot as now used in Bombay. The carts are backed across the set stone paving to the stops, until the discharge pipe is over the opening of the hopper. In the latter is fixed a grating, the bars of which are set close enough to prevent road metal and tiles from passing through them. The hopper discharges into a central tank, called the night-soil tank, with which is connected a masonry water tank, provided for flushing purposes. Running the whole length, and about 7 feet high above the night-soil tank, is fixed a water-supply pipe with two branches, one over each hopper for flushing it and its surroundings and for cleansing the cart if necessary. An ample supply of water is an absolute necessity in a night-soil depot of this description, for it is

requisite to thoroughly dilute with water the contents of a night-soil cart before discharging them into the sewer. The final discharge from the night-soil tank into the sewer is arranged by opening, by means of a lever, a penstock fixed at the lower end of the tank.

Plate 33 shews a useful night-soil depot or Excreta Disposer of small size, designed by the Author several years ago, used exclusively for the emptying of baskets, and time and experience have proved the suitability of this appliance. It consists of a tank holding 50 gallons of water and divided into two compartments. The smaller compartment is fitted with an ordinary annular siphon, the inner leg of which is trapped at the bottom and discharges into a branch drain in connection with the main sewer. Fixed on the top of the other compartment of the tank is a funnel of a size sufficient to take at its top a night-soil basket, which, being inverted, rests on a ledge on the inside of the funnel. An automatic three-gallon flush tank is connected to a flushing rim at the top of the funnel and serves to keep the funnel clear of night-soil. The basket, after being emptied through the funnel into the tank, is flushed by means of the upright water pipe, which shoots the water jet into the basket, thoroughly scouring its sides. The main tank is designed to dispose of three baskets of night-soil for every discharge of 50 gallons of water. Great care must be taken to see that the water pipe supplying the jet for cleansing the basket is so cut off from the water main as to prevent any possibility of it in any way becoming contaminated by night-soil. This should be preferably done by fixing a supplementary tank at such a height as to give the necessary pressure to the jet for cleaning purposes.

Washing Places.—Plate 34, Fig. 1, shews a design of a public washing-place. Such an installation should be paved with stone laid on concrete and jointed with cement.

The paved space is usually divided by a central wall into two compartments, one side being reserved for males and the other for females. On each side of the wall is fixed a water-supply pipe with taps at convenient distances, an open channel being constructed at the bottom of the central wall for the discharge of the water, which drains at the lower end into a trap on a branch pipe drain connected with the nearest sewer: the paving on both sides is sloped towards this open channel. Around the whole of the outside of the paving should be fixed a line of curb stones, rising four inches above the pavement.

Cab Stands.—Plate 34, Fig. 2, shews the construction of a cab stand for a public street. The pavement in this case should be always of set stones. The stand should be 6 feet in width with a slope of 2 inches from either side towards the centre. In the centre a cast-iron trough, 4½ inches deep by 5 inches wide, is fixed, running the whole length of the stand and having an opening at the top, one inch wide, to admit drainage. This metal trough should have a slope of 1 in 100 to one end and be there connected by a trap and a branch-pipe to the nearest sewer. Cab stands may be of any length to suit circumstances, but if of greater length than about 200 feet, should be drained in sections.

Public Dhobi Ghat.—Plate 35 gives a drawing of a public Dhobi Ghat or place for washing clothes. Such a Dhobi Ghat can be made of a size to accommodate any number of dhobis or washermen. The central channel marked A in the section, is a general water tank fitted with a ball-cock to maintain the level of the water. B B are small tanks opposite each compartment, from which the dhobi obtains the necessary water for washing purposes and are filled by hand from the general water tank A. The stone on which the clothes are beaten is marked C, the covered shed being for the bhutti or boiler. The

whole of the ghat is constructed of stone paving set on concrete and jointed with cement. A small charge per month is made for the use of each compartment. A Dhobi Ghat, as above described, is a desirable institution in every Indian town which has a water-supply and a drainage system, in order that all public places where clothes are washed may be brought under supervision and conducted with due regard to cleanliness and proper drainage. The filthy conditions under which clothes are generally washed, where no supervision is exercised and no suitable accommodation provided, cannot fail to be a fruitful source of danger to public health.

CHAPTER IV.

HOUSE CONNECTIONS.

The general principles of house connections adopted in Europe require considerable modification before they can be adapted to the peculiar conditions obtaining in most Eastern Cities. It is desirable, therefore, before describing the best system of house-drainage connections for Eastern Cities, to give a short description of a typical house and the manner in which the towns are often laid out: Large buildings abound, in which it is not unusual to find as many as twenty rooms on each floor, each occupied by a different tenant or tenants, and each furnished with a *nahani* or washing-place, known in some localities as a *mori*. In the bazaars and other thickly populated parts, these houses are often separated only by narrow passages or gullies, which are provided both for drainage purposes and as a means of access to the privies, while the streets are generally narrow and badly paved; and to keep such localities healthy and sanitary is obviously no light task: refuse and rubbish, to save trouble, are generally thrown out of the nearest window, and the consequence of this practice, combined with the fact that the washing-place which is provided in nearly every room is by no means always confined to the purpose for which it is intended, is that the gullies between the houses soon get into a filthy condition and a large staff of scavengers has to be maintained by the Municipal authorities to clean and flush them.

The first method adopted for dealing with these gullies in Bombay was as follows:—A 6-inch stoneware pipe drain was laid in the gully and disconnected from the sewer in the street by means of a running siphon; each waste-water pipe discharged into a trap placed at the foot of it, and was connected to the 6-inch pipe drain by a 4-inch pipe; traps connected with the 6-inch pipe drain were also provided for the privy sullage and a 2½-inch cast iron pipe was fixed at the higher end of the pipe drain for ventilating the same: the whole surface of the gully was finished either with stone paving or with cement plaster.

This system was generally found unsatisfactory, as the traps and pipe drains quickly choked with household rubbish or refuse from the *nahanis*, which resulted in the paving being flooded and the general condition of things being no better than if no pipe drain existed. In time, owing to the constant sweeping and flushing, the stones forming the pavement of the gully became uneven, the joints opened, and the sewage and sullage soaked into the foundations of the houses. For such a class of property, situate in the heart of a thickly populated city, it was necessary, therefore, to design some better system.

The system now prevalent, and one that has given great satisfaction, is to construct open drains in all such gullies. These open drains, which are more fully described hereafter, are 4 inches wide by 10 inches to 11 inches in depth and are constructed at a gradient of not less than 1 in 100. They have the great advantage of being easily swept clean, and, though rubbish may choke them, it can only do so temporarily.

It is most essential that proper care should be taken to prevent gas and foul air from the sewer entering the houses. This is more important here than in Europe, not only on account of the greater quantity of the sewer gas generated, but also because the tenants of the house often

live, eat, and sleep in the room where the *nahani* with its pipe connection is situated.

The depth of the seal in any trap for house drains in India should never be less than three inches. Traps can never be absolutely relied upon, and should be regarded more in the light of a necessary evil, which it seems impossible at present to improve upon: they fail from various causes, such as sewer gas forcing its way through them under pressure, evaporation of water in the trap, siphonage due to a piece of rag or paper being caught part way, and from the water being removed on account of a partial vacuum due to a sudden discharge of water down the pipe connected with them.

Under any circumstances, house connections are an expensive item, and they should therefore be kept as simple as possible consistent with efficiency.

The following few rules may be considered to be applicable to general house-connection work in India, when for any reasons it is preferable to use pipe drains:—

The branch pipe drain connecting a house with the street sewer should be always of well burnt stoneware and of a minimum size of four inches in diameter, while the gradients of such pipes should not be less than 1 in 50.

All such pipe drains should be laid in straight lines with true gradients from one inspection chamber to the other. An inspection chamber should be constructed at every angle in the drain and on long straight lengths at distances of 100 feet.

All pipes should first be laid and fitted dry, previous to any jointing being done. All joints should be caulked with tarred gasket in one length, sufficiently long to entirely surround the spigot end of the pipe, the gasket being driven in as far as possible into the

joint. The joint should then be wetted, and neat Portland cement forced in until the whole space around the spigot is quite full, the jointing being completed with a splayed fillet of pure cement being laid all round it.

Before being covered, the joints of the pipe drain should be tested for water tightness by closing the lower end of the length of pipes and filling it with water to the level of six inches above the top of the highest pipe. If the level of the water does not fall within one hour, the joints may be considered satisfactory.

All inlets to pipe drains should be trapped with the exception of those used for ventilation.

The higher end of the pipe drain should be finished with, preferably, an inspection chamber provided with a ventilating pipe.

Excessive and unnecessary depth of excavation should be avoided.

In the event of a satisfactory gradient not being obtainable, arrangements for sufficient flushing to produce a self-cleansing velocity must be provided.

Plates 36 and 37 shew, respectively, the class of stoneware and cast-iron pipes and fittings used in house-connection works in Bombay. It has been the practice to use 6-inch pipes for all branch drains, except those of very short lengths. This size is in many cases, theoretically, too large for the maximum amount of sewage which the pipes will ever be called upon to discharge, but is adopted for the reason that so much solid matter in the way of sand, ashes, and vegetable refuse is discharged into the branch drains, that pipes of less diameter would constantly become choked.

The intercepting sewer trap shewn in Plate 36 is one of the most necessary and useful traps in use, and whether

the open or closed system of pipe drains is adopted, a house where this is not provided cannot be considered to be properly drained. It is usually fixed in an inspection chamber built at the lower end of the house pipe drain, of a size sufficient to allow of a cleaning rod being easily manipulated. It is provided with a cleaning eye, by means of which any obstruction in the drain between the trap and the public sewer in the street can be removed without disturbing the surface of the road.

The question whether the intercepting sewer trap is or is not desirable, has been freely discussed among Sanitary Engineers. This particular kind of trap was introduced shortly after the illness of our present King (then Prince of Wales), which was attributed to bad drainage. There are many Sanitary Engineers who blame this trap for an increase in the foulness of sewer air and assert that it should be discarded. Certainly, the trap, especially when connected to a 6-inch pipe drain, is not often completely flushed out, and organic matter in course of putrefaction remains in it and becomes very offensive. In colder climates there may be good ground for dispensing with it; but in the East, with its high temperature, the Author deprecates its removal and considers that no house drainage is complete without its presence. The disadvantage of the putrifying matter is far outweighed by the advantage of keeping the sewer air from passing into the branch drain.

There are various kinds of junction pipes shewn in Plate 36. Such junctions should either be quadrant or oblique; and the use of T junctions should be avoided, because these direct the flow of sewage at right angles, instead of obliquely, in the direction of the flow of sewage in the main pipe.

The 6 inches by 6 inches stoneware trap, with a 4-inch outlet, is a common and useful fitting; and where a closed pipe drain is the main conduit for conveying the house

sullage to the sewer, one should always be inserted at the bottom of every waste water down-take pipe to receive the sullage from *nahani* and washing places.

All waste water pipes should be 3 inches in diameter and the joints should be made air-tight with a mixture composed of Portland cement, boiled oil, and chopped hemp, a ring of tarred gasket being first inserted into the joint.

Soil pipes should be universally 4 inches in diameter. The thickness of waste water pipes and soil pipes will vary, but it should not be less than 1/8th of an inch in the case of the former and 3/16ths of an inch in that of the latter.

The trap shewn in Plate 37 is inserted in a *nahani* to prevent the foul air in the down-take pipe from entering the building.

All cast iron pipes and fittings used for house drainage purposes should be coated with Dr. Angus Smith's Solution before use.

The following is the method by which pipes are coated with this solution:—

A tank or bath required for the above process should be of sufficient capacity to allow of the complete immersion of the largest size of pipe to be coated, and should be externally fired in such a manner that the heat from the furnace is evenly distributed over the bottom of the tank.

The coating mixture is made from coal pitch, distilled until all the naphtha is removed, or what is known as Burgundy pitch, and 6 per cent. by weight of boiled linseed oil. Pitch which becomes hard and brittle when cold, should be rejected.

The pipes, which must be thoroughly clean and free from rust, are immersed in the bath when its temperature has risen to 300°F., and are kept there until

they have attained the same temperature; after removal they should be placed on end to drain.

The bath requires careful attention and should be kept, as far as possible, at an even temperature. Over-heating will result in the contents boiling over and insufficient heat will produce too thick a coating.

The mixture will after long use become thick, when a little more oil may be added, but when too thick to produce an even and thin coating it should be removed and fresh materials substituted. Coal tar must on no account be used for thinning, as it will cause the bath to foam.

All inspection chambers should be constructed of 9-inch brickwork, internally plastered with a half-inch coating of cement and sand (1 to 1). At the bottom of the chamber a channel with a half round pipe, of the width and the full depth of the pipe drain, should be constructed. The chamber should be covered with a cast iron air tight frame and cover as shewn in Fig. 23.

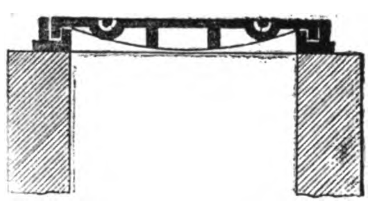


FIG. 23.

The experience after several years' trial in Bombay is that the drain for the conveyance of the house sullage, except the street portion, is better open than closed. This conclusion has been arrived at on account of the liability of the closed drain to chokage, due to the large amount of all kinds of solid matter deliberately or carelessly put into the drain by the inmates of houses.

The width of the gullies between houses varies from 1 foot to 3 feet or more. In the case of narrow gullies the open drain may be constructed in the centre, any rain water falling on the gully being allowed to flow away with the sullage. In wider gullies the drain should be

constructed on one side, as shewn in Fig. 24, and the storm-water channel on the other. In the case where two open drains are constructed, one on each side, the storm-water channel should be laid in the centre.

The class of open drain found most satisfactory is that shewn in Fig. 24. It may be constructed either in the centre or on one side of the house-gully. The invert is lined with 4-inch channel pipes and the remainder, which is of brickwork, is covered with a half-inch coating of cement and sand (1 to 1).

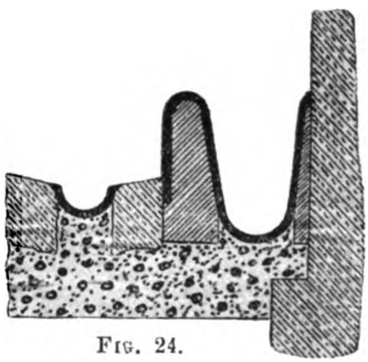


FIG. 24.

The drain is very easily flushed and kept clean; and at the end—between it and the inspection chambers which contain the intercepting sewer trap—is constructed a small silt chamber with a cast iron grating as shewn in Fig. 25. If these small chambers are regularly emptied,

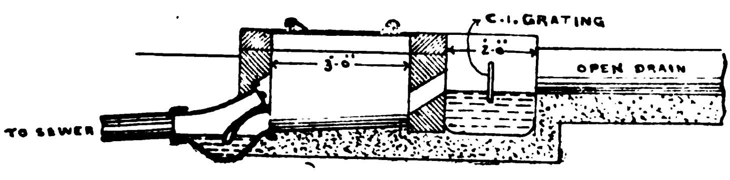


FIG. 25.

the success of the open drain is assured. The minimum gradient at which these open drains should be constructed is 1 in 100.

The practice in Bombay is for the house owner to construct the house drain up to the boundary of his property, as also the inspection chamber with the intercepting sewer trap and the ventilating pipe on

the street end of the drain; and for the Municipal Corporation to lay the connecting closed drain in the public street. The "street connection," as this connecting drain is called, should in all cases consist of a 6-inch pipe drain, which is connected to the street sewer by means of a junction pipe, or in the event of there being no junction pipe, by means of a saddle piece as shewn in Fig. 26.

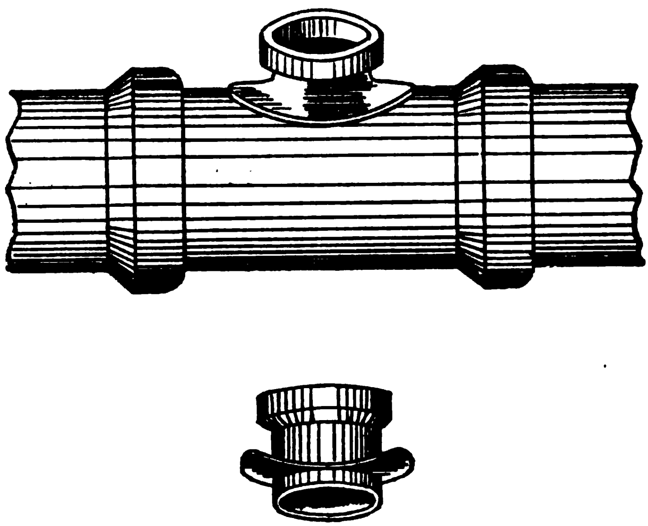


FIG. 26.

An open drain is not applicable to any house where water-closets are in use. For such houses a closed drain must be laid for both sullage and fœcal matter as before described, or an open drain should be constructed for the sullage and a closed one for fœcal matter.

It will be many years before the use of water-closets in any Indian City will become general. The habits of the people are in many ways not suited to them, and caste prejudices often interpose. Wherever practicable, and in the case of houses occupied by the higher class of Natives and Europeans, water-closets are desirable. Various kinds of soil pans for water-closets suitable for Natives are now

made, and a more detailed description of those patterns has been given in Chapter III. For Europeans, similar soil pans to those used in England are suitable here; but preference should always be given to a wash-down pattern as there is less area to foul. All water-closets, whether for Natives or Europeans, should be flushed by means of a three-gallon flush tank, a water-supply tank being provided in a suitable position.

In hotels, clubs, and other institutions, where hand basins are provided and urinals, apart from water-closets, are generally considered necessary, there is practically no departure made in either the construction or method of drainage from the ordinary English practice. In buildings set apart for the sole use of Europeans, urinal basins are generally used, and for Natives the pattern shewn in Plate 23 will be found perfectly satisfactory. Such appliances should always be placed against an exterior wall, so that a length of pipe drain under the floor of the building may be avoided. Efficient flushing appliances are essential and of course a reliable and ample water-supply is imperative. Any thing more offensive and dangerous than a water-closet without water in hot tropical weather it would be hardly possible to imagine.

The building bye-laws in Bombay now specify that all water-closets and privies should be cut off from any living room by at least a three-foot air space on all sides; but this rule has only come into force in recent years, and in the majority of houses in the City the privies are not detached in any way from the main building, but on the other hand are often built against an interior wall in a convenient position. Plate 38 shews in detail the class of privy to be found in most Indian houses. Such a privy, from a sanitary point of view, must be considered insanitary. Looking, however, to the present sanitary education of the people, it is probably the best arrangement that can

be provided when a water-closet is out of place, and it falls in with the caste prejudices of the people, who prefer it to all other arrangements. The sloping part of the privy, which receives the night-soil, and the sides should preferably be lined with plate glass, as this material is not only incorrodible, but fœcal matter does not readily cling to its surface.

The privies are usually connected with a shaft, constructed of brick-masonry, plastered with lime or cement, and of an internal measurement of 18 inches by 18 inches. But latterly these masonry shafts have been replaced by 6-inch stoneware pipes—an undoubted improvement. After a time, these shafts must naturally get coated with fæcal matter and become insanitary, as they have no flushing arrangements and their state of cleanliness depends solely on the amount of water thrown down them by hand through the privies. The shaft discharges its contents into a basket as previously described.

Some years ago, the Author designed and carried out an intermediate system to be used in connection with privies. This consisted of the substitution for the usual basket of a stoneware soil pan at the bottom of the shaft. Into this pan everything from the privy was discharged. An automatic flushing tank was fixed on the wall outside the privy, containing from 10 to 20 gallons of water according to the number of privy seats. It was connected with the soil pan, and on the water being discharged the contents were flushed through a trap into a branch drain connected with the sewer. The soil pan was made of such a shape that solid matter, such as stones and tiles were retained in it, and the sole work of the sweeper was to remove these materials, everything soluble being flushed away. The flushing tank, besides being automatic, can also be discharged at will by the sweeper when only partly full.

This arrangement proved to be useful and sanitary and free from smell, and did away with the hand removal

of fæces; but it proved wasteful in regard to the amount of water used.

Plate 39 shews the above system in detail.

The universal term *nahani* is used to describe a small sink in an Indian house, with or without a water connection either inside or outside a room, built primarily for washing purposes, but often used indiscriminately for urinating and defæcating, particularly by children. It is usually about 3 feet square, constructed in a corner and raised some 4 inches above the surface of the floor, with a concrete or brick-work surface plastered with lime or cement, and surrounded on the open sides by a small kerb or a dwarf wall. All *nahanis* are connected to the waste water pipe fixed to the outside of the house by means of a *nahani* trap, previously described or a Tee-shaped pipe. If the latter is used, the discharge into the waste water pipe is through a cistern head, but in the case of a *nahani* trap, it is connected direct with the waste water pipe, which is carried up above the building as hereinafter described.

Ventilating Pipes.—No house drainage would be complete without a regular system of ventilation. The theory of ventilation is that (*a*) the air of the drain being at a higher temperature than the external air and therefore lighter, a current is formed through the outlet shaft; (*b*) that the warm air, carrying a certain amount of water vapour which is lighter than dry air, causes it to rise; (*c*) that wind blowing across the open end of the outlet shaft creates a slight vacuum. On the sewer side of the intercepting trap, a 3-inch cast iron pipe should be fixed to the drain and carried up the side of the house to a height of five feet above the eave of any roof that may be within twenty feet thereof. The inspection chamber at the lower end of the pipe drain should be connected with

a fresh air inlet pipe fitted with a mica valve as shewn in Fig. 27. This fresh air inlet pipe should be placed against

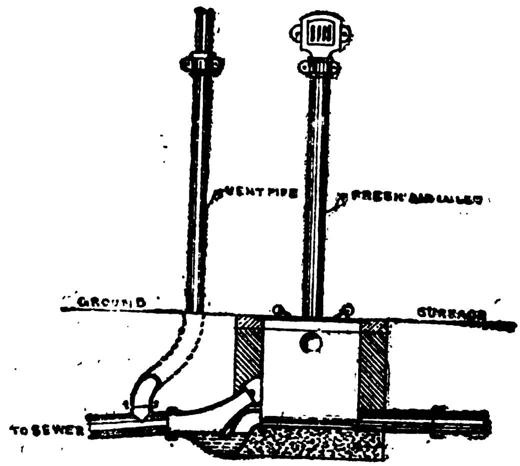


FIG. 27.

a wall or a post, whichever is most convenient, and should be about six feet above ground level. The head of every pipe drain should be ventilated with a 3-inch cast iron ventilating pipe, similar to the one hereinbefore described. In the event of a pipe drain being more than 100 feet in length, a ventilating pipe should be fixed midway and connected with the intermediate inspection chamber. All soil pipes should be carried up to five feet above the eaves of the roof. In case of a tier of water closets one above the other, a 2-inch anti-siphon pipe should be taken from each water-closet, except from the one on the highest floor, and carried up above the roof the same height as the soil pipe. In the event of waste water pipes being fitted with *nahani* traps, each of these pipes should be carried up as a ventilating pipe five feet above the eaves of the roof of the house. All such pipes carried up above the roof should be protected at the top with a wire dome.

Gullies.—As already stated *gullies* are the narrow passages left between houses for drainage purposes and also to give access to the privies and to admit light and air. Such *gullies* should always be paved with a non-porous stone set in concrete and jointed with cement, or should be constructed of concrete finished off with a coating of cement plastering (1 to 1) one inch in thickness: the surface of the *gully* should slope towards the centre as shewn in Fig. 28 and also longitudinally towards the street.

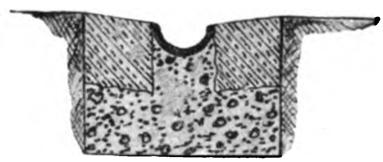


FIG. 28.

At the lower end of the *gully* and in the centre of it a jump-weir should be constructed as shewn in Fig. 29,

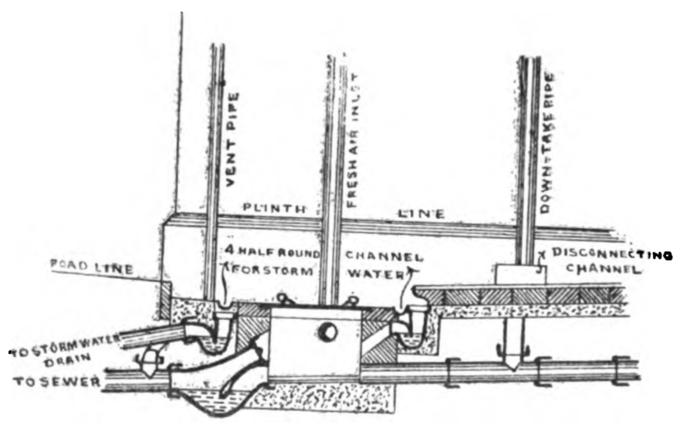


FIG. 29.

so that while any ordinary flow of sewage would discharge over the jump-weir into a trap connected with the sewer, a rush of storm-water would pass over the opening and discharge into another trap connected with the storm-water drain. In the event of its being considered necessary to

flush the *gully*, a flushing tank as shown in Plate 40 will be found suitable. This tank is fitted with an annular siphon and a reverse ball valve and should have a capacity of from 20 to 50 gallons.

All down-take pipes, ventilating pipes, and soil pipes should be tested for efficiency and soundness by means of the smoke test as follows:—A smoke rocket should be inserted in the bottom of the cast iron pipe, if it is not connected directly with the drain, or, if otherwise, into the inlet in the nearest inspection chamber, and fixed there so that all the smoke will pass up the pipe. As soon as the smoke commences to issue from the top of the ventilating pipe, the pipe should be closed at its top end to enable the smoke under pressure to find its way out of any leaky joints or cracks or perforations in the pipe.

For house connection purposes, houses in the City of Bombay are divided into the following three classes:—

CLASS I.—Detached houses in compounds.

CLASS II.—Attached houses without gullies.

CLASS III.—Houses of all other classes.

These classes are further sub-divided into (A) and (B) thus:—

SUB-CLASS A.—Houses where it is desirable to drain the premises by a pipe drain.

SUB-CLASS B.—Houses which are not within 100 feet of a Municipal sewer.

CLASS I.—With houses of this class, open drains as branch drains should be made use of as far as possible, but where water-closets are constructed, then the branch drains connected with the closets must be closed.

CLASS II.—In houses of this class, an open drain is not possible, and therefore the closed pipe drain must be laid under the building.

The conditions laid down in Bombay in regard to the construction of drains which have to be laid to pass beneath any part of a dwelling house are as follow:—

"Every owner shall so construct a drain only when any other mode of construction is impracticable, and not even then without the written permission of the Municipal Commissioner. It should be so laid that there shall be, between the top of the pipe and the surface of the ground under such building, a depth at least equal to twice the internal diameter of the pipe drain.

"The drain shall be laid in a straight line for the whole of the distance beneath the building and be completely embedded in and covered with good concrete, nowhere less thick than 6 inches outside the drain, measured in any direction.

"At each end of such portion of the drain, beneath the building, a 6-inch trap shall be inserted outside the building, giving a drop of at least 2 inches into the contained water with a 4-inch inspection inlet brought up to within 9 inches of the surface, and covered with a cast iron grating 9 inches by 9 inches set in a frame of stone or timber standing up 2 inches above the general surface so as to exclude storm-water. On the lower side of the siphon, a 4-inch stoneware branch pipe shall be connected with the drain, and brought up above the ground and continued with a cast iron pipe above the roof of the building for ventilation purposes, in addition to such means of ventilation as are ordinarily directed to be provided."

CLASS III. —In all such houses, the premises should be drained by means of an open drain. The only exception to this is in the case where one or more sides of a house abut on a public road, under which circumstances there is no

alternative but to provide a closed pipe drain. In houses of this class also, where water-closets are constructed, closed pipe drains must always be laid.

SUB-CLASS A.—In regard to this class of houses, sanction is accorded to owners desirous of having closed drains, instead of open, but in such cases the following conditions are laid down:—

"The pipe drain shall be laid at a gradient of not less than 1 in 50. The connection between the street connection pipe and the branch drain with the inspection chamber, the intercepting sewer trap, and the fresh air inlet pipe, shall be made at the house-owner's expense. Inspection chambers shall be placed at every 100 feet or less if there is any change of direction, and built in accordance with the conditions prescribed in the earlier part of this Chapter. The branch drain must be ventilated by a 3-inch cast iron ventilating pipe, and every ventilating pipe, soil pipe, and anti-siphon pipe must be protected at the top by a wire dome and carried up in accordance with the conditions before laid down. *Nahani* traps should be provided for every *nahani* except those on the ground floor. All waste-water pipes must be of cast iron three inches in diameter, and all soil pipes four inches in diameter. All soil pans for water-closets must be of porcelain or glazed stoneware, provided with a flushing rim and a trap of similar material. Every water-closet must be provided with a 3-gallon tank for flushing purposes; and in cases of tiers of water-closets, the anti-siphonage pipes must be fixed as hereinbefore described."

SUB-CLASS B.—In regard to this class of buildings, there is at present no law by which the Corporation of Bombay can compel the house-owner to connect his premises with a Municipal sewer in the public roads. In such cases it often

happens that there is no sewer except at a very considerable distance from the house, and therefore, unless it is practicable to sanitarily dispose of the sullage in a garden for the irrigation of plants, it must be drained into a cess-pool. In a case where a cess-pool is constructed, its capacity below the invert of the drain discharging into it should be sufficient to hold a twenty-four hours' flow. Such a cess-pool should be ventilated by a cast iron or galvanized iron pipe, not less than three inches in diameter, and of such a height as to ensure its causing no nuisance.

It is desirable to have a cess-pool for privies separate from that for *nahanis* and the size of this cess-pool should be calculated to have a capacity of 3 cubic feet per privy seat with a minimum of 10 cubic feet.

Cess-pools should always be emptied once every twenty-four hours, and preferably at night.

Such a cess-pool should be constructed of brickwork on concrete internally rendered with a ½-inch layer of cement and sand (1 to 1). The walls of the cess-pools should be brought up to six inches above the surface of the ground, so that surface water may not be able to flow into it, and covered with an air-tight cover to prevent noxious odours escaping.

No cess-pools should be constructed within 20 feet of any well used for drinking purposes, for although the cess-pool may be constructed so as to be perfectly water-tight, it is always liable to overflow.

It is desirable also in houses of this class to make use of open drains rather than closed drains. Many instances are within the knowledge of the Author where the sewage of such buildings has been successfully dealt with by small Septic Tanks and Filters or by a series of filters, the

effluent being run into masonry tanks and used for gardening purposes. Such arrangements, if constructed scientifically, are quite satisfactory.

Plate 41 shews a house fitted with water-closets and drained, according to the arrangements already advocated, by means of a 6-inch pipe drain. It will be seen that the drain is laid at a gradient of 1 in 50, and that at its higher end there is an inspection chamber covered with an air-tight cast iron frame and cover. Connected to this inspection chamber is a 4-inch cast iron soil pipe from the water-closets. At the lower end of the pipe drain is another inspection chamber, into the brickwork of which is built an intercepting sewer trap with a cleaning eye: the cap of this cleaning eye should always be securely fixed, as otherwise gas from the sewer will have a free discharge into the chamber. Connected with this chamber there is also a 3-inch fresh air inlet pipe fitted with a mica flap valve, which supplies fresh air to the whole length of the pipe drain between the inspection chambers. Under each waste-water pipe is fixed a 6-inch by 6-inch trap, which is connected to the pipe drain by means of a 4-inch branch pipe.

All the waste-water pipes are three inches in diameter, coated with Dr. Angus Smith's solution, and carried up five feet above the eaves of the roof, the ends being protected with wire-domes. The *nahanis* on each of the floors are connected with the waste-water pipes by means of *nahani* traps. The soil pipe from the water-closets is four inches in diameter, and is also carried up five feet above the eaves of the roof of the house. Each soil pan is trapped and connected with the soil pipe by means of 3-inch branches. Alongside the soil pipe is a 2-inch anti-siphon pipe connected to the traps of the soil pans on the ground and first floors. A strong tank is fixed above the water-closets to provide a constant supply of water to the 3-gallon tanks for flushing the water-closets

Connected with the pipe drain and between the intercepting trap and the sewer is a 3-inch ventilating pipe, which is carried up the side of the house to five feet above the eaves of the roof, thus preventing the seal in the trap being forced by a pressure of gas in the sewer. The fresh air, which enters by means of the mica flap valve connected with the inspection chamber at the lower end of the pipe drain, is discharged at the higher end of the drain through the ventilating pipe which is connected to the inspection chamber at that end. All soil pipes and waste water pipes are trapped at their connections with the buildings and carried up above the roofs as ventilating pipes. Each waste-water pipe is disconnected from the pipe drain at the bottom, and discharges its sullage through a short length of channel into a trap. The water-closets are entirely separated from the main buildings by a passage 3 feet wide.

It will thus be seen that the whole of the building is guarded against gas entering it from the sewer or pipe drain.

The storm-water falling on the *gully* is discharged over a jump-weir into a trap connected with a storm-water drain in the street.

Plate 42 shews the same class of building with Native privies and drained by means of an open drain. The open drain is constructed, as described earlier in this Chapter, at a gradient of 1 in 100, and at its lower end it discharges into a small catch-pit fitted with a grating. This catch-pit is to arrest heavy matter in the sewage, and the grating is to intercept floating substances, such as leaves, etc. The sullage, after passing through the catch-pit, may discharge into an inspection chamber, into the wall of which is built the intercepting sewer trap, as explained in the description of the previous house.

The privy sullage discharges on to the higher end of the open drain through the open sides of the basket placed

under the shaft of the privy. The waste-water pipes discharge directly on to the open drain without any traps. In two instances in this house the discharge from *nahanis* is directly on to cistern heads, but in one instance the *nahanis* discharge through *nahani* traps, as explained in the description of the previous house, and in this case the waste-water pipe is carried up above the eaves of the roof and finished with a wire-dome.

The privies are separated from the main building by a passage three feet wide, and discharge their contents into a 6-inch stoneware pipe acting as a privy shaft. The ventilation of the sewer is provided for by a 4-inch stoneware pipe connected with the 6-inch pipe drain on the sewer side of the intercepting sewer trap, and continued by a 3-inch cast iron pipe carried up above the eaves of the roof of the house and finished with a wire-dome. The storm-water from the *gully* is discharged by means of a jump-weir into a trap fixed at the lower end, and connected with the storm-water drain in the street.

It may be argued, perhaps rightly, that the house connections described in this Chapter are in many ways too complicated and expensive, except for large cities with high buildings, and that in a mofussil town something much simpler would suffice. Some years ago the Author visited Secunderabad to advise on the drainage of the town including the house connections. After inspecting many of the houses, the arrangement as shewn in Plate 43 was recommended. This consisted in connecting the washing place or *nahani* at the back of the house by means of a 4-inch by 4-inch stoneware trap and a 4-inch stoneware pipe to the pipe sewer in the street. On the same line of the 4-inch pipe, but lower down than the *nahani*, is connected the privy of the premises, fæces being caught in a basket and the sullage draining through a 4-inch by 4-inch stoneware trap to the 4-inch pipe drain.

At first it would appear that the absence of any sewer trap near the junction of the house drain with the sewer would be likely to allow sewer gas to pass up the house drain and, in the event of the water in the traps having evaporated, escaping within the precincts of the houses. On the other hand, however, it must be remembered that practically no night-soil passed into the sewers, and that the sewage was of a weak and more or less inoffensive nature. It was, therefore, very improbable that any serious accumulation of sewer gas would take place, and even if this remote contingency did arise and a nuisance was noticed, such nuisance would be easily remedied by pouring a little water into the traps. Further, no connections of any kind were made with the interior of the houses, and taking all these facts into consideration, the Author was satisfied that such a comparatively expensive accessory as a sewer trap could in this instance be dispensed with.

The end of the 4-inch drain should be ventilated by means of a 3-inch pipe, carried up above the roof or fixed on a post ten feet above the ground; but if for economy it is desired not to erect a ventilating pipe in all cases, it may only be done at the higher parts of the district.

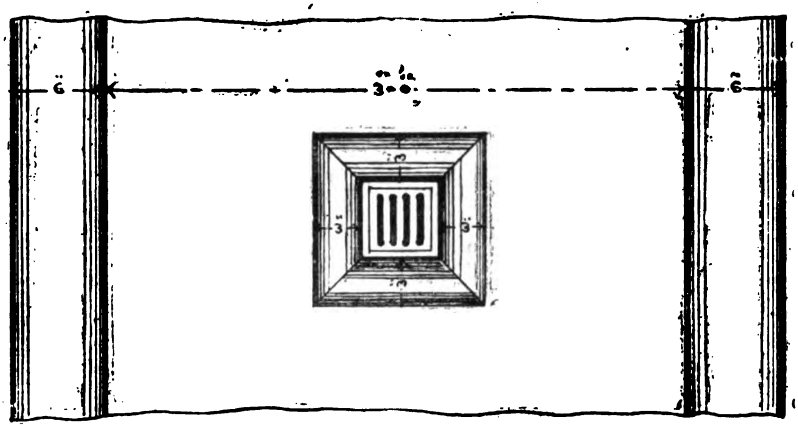
A washing place may be constructed of any size to suit the premises for which it is intended. It should be built of concrete rendered with cement plaster, the walls surrounding it being of brickwork; three sides may be raised, if desired, to a height convenient for privacy.

The slope of the washing place should be towards the trap, which should be covered with a grating.

This arrangement is economical and eminently suitable for the one-storeyed buildings with small compounds which are mostly met with in the mofussil towns, and might be applied in many of the old houses in villages.

Fig. 30 below represents a detail drawing of the plan and cross-section of the washing place referred to on page 140:—

PLAN.



CROSS SECTION.

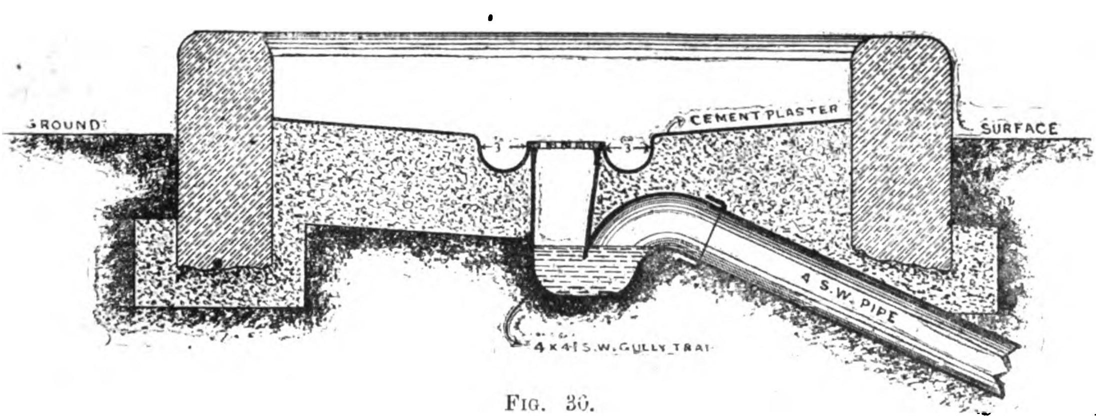


FIG. 30.

In the out-lying villages of Bombay, where drainage is necessary, public detached washing places and latrines for the use of small and poorly-built houses should be erected, instead of each individual house being given its own convenience connected with the pipe sewer.

Drainage of Horse Stables.—Much experience and knowledge have been obtained in Bombay as to the best

method of draining stables, for there are many very large stables for the reception and sale of the immense numbers of Arab and Australian horses which are annually imported.

For horse stables, both public and private, it is a good plan to construct the floor of each stall with a layer of 6 inches of lime concrete laid at a slope of 3 inches in 9 feet or 1 in 36. Above the concrete should be spread a 3-inch layer of good *muram* well rammed and finished off to the same slope as the concrete. Meeting the *muram* and at right angles to the stall should be constructed a V-shaped channel, 12 inches wide, formed of stone or other suitable material. *Muram* is only advantageous when it is carefully looked after, and any hollows formed by the feet of the horse should be quickly filled up and rammed. *Muram* is not a suitable material if not kept in repair. Another arrangement is to plaster the concrete with lime, forming a small channel in the centre of the stall to meet the V-shaped channel at the front. Stone is not a suitable material with which to pave horse stables. It is very hard and apt to become under certain conditions slippery, and in the event of a horse falling on it great damage is often done to the animal. The channel in front of the stall should have a gradient not less than 1 in 100 discharging into a 6-inch stoneware trap connected to the branch drain. In England, brick with corrugations is much used for the paving of stables. This probably is the best method of all; but in this country, as a rule, suitable bricks for the purpose are not easily obtainable.

Buffalo Milch Cattle Stables.—In this class of stables *muram* is of no use, and the floor of every such stable should be paved over the whole area with stone paving laid on a 6-inch bed of concrete. This is rendered necessary because of the frequent washing which buffaloes receive daily. The paving should slope at an inclination of 1 in 60 towards an open stone channel. The channel,

as in the case of horse stables, should be V-shaped with a gradient of 1 in 60 towards a trap on the branch pipe drain. In connection with a stable of this class, and on account of the large quantity of solid matter carried in the sewage, a catch-pit should be constructed as in Fig. 31.

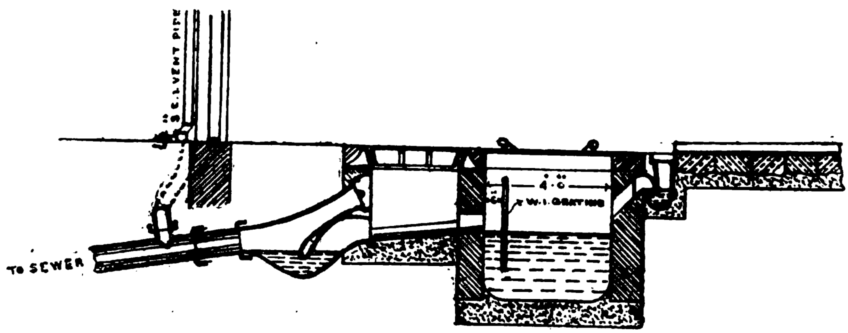


FIG. 31.

During the dry season much of the buffalo excreta is removed by hand and, mixed with hay or straw and the sifting of cotton seed, made into cakes for fuel purposes. These cakes, when dried in the sun, are ready for use, and in many parts of India are almost the only fuel available. The catch-pit should be placed at a point where the stable drain ends and the branch pipe drain commences. It should be 3 feet by 4 feet by 5 feet deep, and be provided with a wrought-iron grating, the bars of which should be fixed half an inch apart to prevent the stable litter passing through into the branch drains.

Bullock Stables.—As a general rule, no special drainage is required for bullock stables, a foundation of good well rammed *muram* being all that is necessary, for the droppings of bullocks are much in request and are largely used for the plastering of the floors of living rooms which have earthen floors. Mixed with fine red earth, bullock excreta form a plaster which has a considerable binding property, and is rendered by the ammonia contained in it a safeguard against fleas and other vermin.

CHAPTER V.

SEWAGE DISPOSAL.

The best method of sewage disposal is always a most difficult question to decide, as a false move may often have far reaching and very serious consequences. The question therefore should invariably be given the most deliberate and painstaking consideration. The difficulties which are met with in many inland English towns do not as yet exist in India. Land in England is often only available at a prohibitive price, and legislative restrictions are rightly placed on the discharge of sewage into rivers.

The different systems of disposal, any of which may be adopted according to local circumstances, may be classified as follows:—

(1) Dry Earth.
(2) River Outfall.
(3) Sea Outfall.
(4) Land Irrigation and Filtration.
(5) Precipitation.
(6) Electrolysed Sea Water.
(7) Biological Treatment.

Dry Earth.—In India, and in fact in most Eastern countries, the dry-earth system was the earliest method adopted for the disposal of sewage and is even now the most usual. In sparsely populated districts, this system, if efficiently carried out, still finds approval. The fæcal matter is collected, removed, and buried outside the town. The sullage water, if not removed by carts, finds it way

through open channels to pits, where it is allowed to soak into the ground. The usual procedure is to remove the fæcal matter to trenches and cover it with earth, and the mistake is often made of excavating these trenches too deep to allow of the bacteria dealing efficiently with the fæces. Trenches should be three feet wide by nine inches deep and one foot apart, and covered with soil slightly raised above the surrounding level.

With increased education and the march of science in sanitation, this system of disposal is doomed and calls for no further comment.

River Outfall.—The sewage of towns situated on the banks of rivers is usually discharged into these rivers, but this should never be done without some preparatory treatment. The degree of purification required depends upon the relative volume of the sewage to the minimum flow of the river, and in cases where, compared with the amount of sewage, the volume of the river is large, it is not generally necessary to construct works which are expensive or of great magnitude, as the river may be safely relied upon to complete the final purification of the effluent.

Unfortunately, however, the authorities of many Indian towns situated on the banks of large rivers give little consideration to the pollution of such rivers and make no attempt to purify the sewage before it is discharged into them. Many of the rivers are sacred; yet the water from these and all others that are perennial is generally used by the inhabitants of their banks for drinking, bathing, and all other domestic purposes, so that the discharge of crude sewage into them becomes little short of criminal; and there is no doubt that such neglect is responsible for the frequent occurrence of cholera and other diseases in epidemic form in many of the towns of this country. Rivers in India are apt to run so perilously low in the hot season that under no circumstances whatever should sewage

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be permitted to be discharged into them without having previously been submitted to some form of purification. Suitable land is always available and any large expenditure on works rarely necessary.

Sea Outfall.—In discharging a large bulk of sewage into the sea in the proximity of a town, great care is necessary to select a position where the sewage will not be thrown back on to the foreshore, as this is liable to cause a most offensive and, as time wears on, an increasingly dangerous nuisance. A most careful study of the tides should be made, and for this purpose float observations at all states of the tide and prevailing wind and weather should be most carefully taken and considered together. The greatest difficulty occurs during neap tides, when the range of tide is not great and sewage is likely to remain for some hours in the neighbourhood of the outfall. A sea outfall should always be taken out as far as possible from the shore, but never to a less distance than will ensure the sewage being discharged into several feet of water, even at the lowest spring tide. The liquid of the sewage rapidly becomes diffused in the body of the sea water, but the solid matter may persist for some considerable period, especially as sea water delays the oxidation of the solid organic matter and it is not until some hours after discharge that purification sets in whereby it is broken up and dissolved. Owing to its specific gravity being less than that of sea water, sewage floats on the surface, open to the influence of both tide and wind ; and, if carried down to a foreshore, it is liable to cause dangerous deposits. The experience at the outfall in Bombay shews that the sewage discharged on an ebb tide is carried for a considerable distance along the coast towards the residential part of the island, and is not all broken up by the sea for at least four hours after its discharge from the outfall. In a subsequent chapter this matter will be further referred to and certain float observations explained.

Consideration should be given in a sea outfall to the question of the local fisheries. Fresh sewage discharged into the sea does little harm—in fact, in Bombay, it is popularly believed to have very largely increased the number of fish on the part of the coast concerned. Putrefying sewage is, however, dangerous, and will destroy or drive away fish. Sea birds are great scavengers and greedily eat all floating matter around an outfall that they can get hold of, but they also avoid putrid sewage. Sewage in India may be considered to be fresh until it is six hours old.

Land Irrigation and Filtration.—Where neither river nor sea disposal is available, sewage is sometimes deposited on a reserved area of land, in which case the soil is relied on for filtering and oxidising it. Any land is, to a greater or less extent, useful for sewage irrigation, but a sandy calcareous or porous loamy soil is the best. Clay land is not well adapted for this purpose. Suitable land should be laid out in level beds, and the sewage applied in turn to each bed. If a porous stratum of sand or gravel underlies the beds, the liquid will naturally drain away with the subsoil water, but in certain cases it will be found necessary to insert underdrains to carry off the liquid. The drains should be laid at a minimum depth of three feet, and in such a manner as to prevent direct vertical percolation into them. Land used for sewage filtration purposes should be constantly ploughed or turned over to allow of æration, suitably cultivated, and kept free from weeds or anything that would choke the surface of the ground. Porous soil under advantageous circumstances will dispose of 30,000 gallons of sewage per acre per day. The worst soil is probably heavy clay soil, which will not safely dispose of more than 5,000 gallons per acre per day. If possible, sewage should not be discharged on to land without previous treatment

in order to remove the solids, as it will rapidly coat the land with a layer of decomposing organic matter, which will hinder the action of the ærobic bacteria in the soil and quickly create a nuisance.

Where previous treatment cannot be resorted to, the intermittent application of small quantities of the sewage should be followed in order that the liquid may drain away and the solids be broken up, thus permitting air and oxygen to refill the interstices of the soil. The process is naturally slow, for until air has reached all the interstices of the soil, the purifying action cannot recommence.

The amount of oxygen available varies with different soils and is at the best limited; and further, the underground circulation of air is very slight, and without oxygen the ærobic bacteria cannot thrive.

Precipitation.—Under this head is included any system which depends on chemical treatment of the sewage, preparatory to its being discharged to the sea, river, or land, in order to precipitate the solids and deodorise or disinfect the liquid. Such treatment is rarely necessary in the East, where land is generally available for irrigation purposes and the sewage is for the most part what is known as domestic, rather than trade, sewage. A good precipitant must be cheap and should cause a rapid subsidence of all organic matter in suspension. It should not be actively or cumulatively poisonous, otherwise it would be dangerous to human and animal life. It should have no distinctive colour, as that would arouse sentimental objections; and if a chemically treated effluent is to pass into a stream or be used for the irrigation of crops, the resultant effluent should be neutral or slightly alkaline.

A large variety of processes have been tried in Europe, but all are expensive and create a great amount of sludge;

and for the reasons given above, it is not proposed to go into them in detail.

Electrolysed Sea Water.—Some years ago, shortly after the outbreak of the first Plague epidemic, when every promising disinfecting system was eagerly considered, an experiment was tried in Bombay of electrolysing sea water and mixing it with the sewage in the sewers so as to destroy organic matter. The system was invented by a Monsieur Hermite, a Frenchman, and has been tried in several places on the Continent and at one or two places in England with a certain measure of success. In this system sea water, or, in default thereof, an aqueous solution of chloride of magnesium and chloride of sodium, is subjected to what is known as "Electrolysis." Under the influence of an electric current the water and the salt are decomposed; and as a result of this decomposition, at the positive pole of the battery, an oxygenated compound of chlorine—very unstable and possessing a considerable oxidising and consequently disinfecting power—is obtained, while at the negative pole is formed an oxide which has the power of precipitating certain organic substances. The sea water, or its equivalent aqueous solution, when subjected to the action of the electric current as described above, is called electrolysed sea water, and is a good disinfecting liquid. It is practically inodorous, but it is a powerful antiseptic. It destroys microbes, renders suphuretted hydrogen innocuous, and effects a complete sterilization and deodorization of all liquid matter. The installation necessary for this system of disinfection comprises (*a*) a central station containing a dynamo and an electrolysing apparatus, a pump to raise the sea water, and tanks for the storage of the same, unless it can be obtained at all states of the tide, and also tanks for the storage of electrolysed sea water; and (*b*) the provision of a separate system of mains, service-pipes, and domestic

fittings for distribution of the fluid in the same way as in the case of ordinary water or gas supply, with branches near the edge of the road to flush the sewers and storm-water drains, or to water the streets with the disinfecting fluid.

The electrolysers are of three sizes: Size A consists of 200 platinum electrodes and 54 zinc disks; B consists of 104 platinum electrodes and 28 zinc disks; and C consists of 44 platinum electrodes and 12 zinc disks. Electrolysers of the first size are useful for industrial requirements. Those of the second are smaller and better adapted to installations on a small scale, such as those for hospitals; and those of the size C are only suitable for still smaller institutions. Several electrolysers can be simultaneously used by connecting them in a series. It is said that the maximum grouping that can be effected advantageously is 10 electrolysers worked by a single dynamo.

The current sent into an electrolyser of type A is generally from 1,000 to 1,200 amperes, of type B from 500 to 600 amperes, and of type C from 250 to 300 amperes. The electro motive force (E. M. F.) required in all cases is from 5 to 6 volts for each electrolyser. The dynamo required to give off these currents is similar to that used for electro-plating and other similar purposes, and its distinguishing feature is its capability of producing a large amount of current at a low potential.

The installation fixed in Bombay consisted of two electrolysers capable of producing 1,000 grammes of chlorine per hour, or 440 gallons of electrolysed sea water containing 0·5 grammes* of chlorine per litre. Assuming the dynamo worked for twelve hours a day, the amount of electrolysed sea water produced should be 5,280

* Gramme is a French weight and is equal to 15·432 grains Avoirdupois Litre is a French measure and is equal to 1·7607 British pints.

gallons. When first started, the installation was worked in connection with a night-soil depot, which disposed of 74 tons of night-soil per day. It was found that 0·5 of a gramme of chlorine was required to disinfect or deodorise one litre of sewage in ten minutes, and therefore 16,576 gallons of electrolysed sea water were required to sterilize the whole of the night-soil of the depot. Much good was done by the use of this electrolysed sea water in lessening the smell of the night-soil depot and no doubt in sterilizing the fæcal matter. An experiment was tried by discharging the fluid straight into the sewer, but the quantity of the fluid produced was not large enough to make any appreciable difference in the large bulk of sewage, which flowed at the rate of 3,500 gallons per minute. The experiment was continued for thirty-four days, during which time 22,000 grammes of chlorine were produced per day, equal to 748,000 grammes or 15 cwts. of total production, at a cost of Rs. 1,039-6-1 or Rs. 1,386 per ton. Unfortunately, however, for financial success, good commercial chloride of lime, containing 30 to 35 per cent. of free chlorine, cannot be purchased in Bombay for less than Rs. 260 per ton, which would bring the actual cost ot chlorine to Rs. 780 per ton, or little more than half the cost of producing the same amount of chlorine by electrolysing sea water, even without taking into consideration the interest on capital expenditure necessary in the latter case.

The plant was tried for a further period, but with very little difference as regards cost. The fluid was also used in Bombay for flushing gullies and disinfecting privies, but the cost of cartage made the process more expensive than ordinary disinfectants. On account of expense, therefore, this system is only recommended for such places, if any exist, where the price of other good disinfectants is so exorbitant as to justify it.

Biological Treatment.—Of late years the knowledge of the biological treatment of sewage in Europe has rapidly advanced. The Royal Commission on Sewage Disposal has brought together the experiences of all the greatest Sanitarians in England, and it will almost appear that the present state of our knowledge has now so far advanced as to leave little to be learnt in the treatment of ordinary (as opposed to trade) sewage. It is not proposed to refer at any great length or in detail to this important subject, because there are many standard works written, which deal entirely with the question of Biological Treatment. The *Interim Report of the Royal Commission* (Volume 11, Evidence) is strongly recommended to students and others interested in the subject.

Before sewage can be thoroughly purified by a biological process, it must undergo two changes. The solid organic matters must be liquefied and the complex nitrogenous and other organic compounds in the liquid of the sewage split up into their simpler forms, and the whole must then be oxidised. To obtain these changes, sewage must be dealt with first by anærobic and secondly by ærobic bacteria—terms invented and first used by Pasteur. All sewage contains within itself the necessary bacteria for its own purification, and it has been proved that these organisms will quickly grow and multiply in water-carried sewage and rapidly liquefy the solid matters and finally set up the oxidation of the organic matter, changing it into harmless forms. Mr. Scott Moncrieff, a Civil Engineer, claims to be the first to have recognised that organic matter in sewage could be dealt with by micro-organisms contained in the sewage itself. These organisms are classified into anærobic and ærobic, *i.e.*, those whose work is performed in the absence of free oxygen and those whose very existence depends upon the free access and presence of free oxygen.

The anærobic treatment of the sewage, which produces the liquefaction of the solids, preferably takes place in a

tank constructed in such a manner that the velocity of the sewage on entering it is so reduced that the solids are deposited and that the organisms can thrive in it and liquefy the organic matter during its progress through the tank. For this to be efficiently performed, a tank should be large enough to hold from 8 to 24 hours' supply of crude sewage, according to strength. Such a tank is usually called a "Septic Tank," which is a name given to it by Mr. Donald Cameron, M.Inst.C.E., the late City Engineer for Exeter. The Author, however, prefers to call it a "Liquefying Tank."

When sewage has undergone anærobic treatment for the specified time, it will be almost wholly without oxygen, that gas having been converted into carbonic acid gas by the decomposing organic matter produced by the mixed organisms which arrive in the tank in the sewage.

The next and second process of purification is performed by the action of the ærobic bacteria which are the organisms that live only in the presence of atmospheric oxygen. These bacteria will work under two conditions, *viz.*, in suitable land, which should contain lime or some other base, or in an artificial filter constructed of some material which will hold air in its interstices. It must be remembered that in all artificial filters we only imitate the process which nature performs for us in land; but in the case of land, however, it is only the first few inches which are usefully employed by the ærobic bacteria, whereas in an artificially constructed filter the whole of the depth can be employed, if the filter is properly constructed. The chemical change made by the filter in the effluent from the liquefying tank is the conversion of the various nitrogenous substances, such as free ammonia, into the harmless compounds of nitrites and nitrates.

The less free ammonia and the more nitrates found in the effluent, the greater the degree of purification. This

second change is made with extraordinary quickness— often within ten or fifteen minutes.

Much attention has been given to the question as to whether biological treatment destroys the pathogenic germs that may exist in the sewage, but it appears that there is at present no acknowledged method which enables a bacteriologist to say with certainty that a sewage effluent is without pathogenic germs. However, as it is unlikely that a sewage effluent, in its condition as an effluent, would be used as potable water, this question can be considered as an entirely separate one to that of the purification of the sewage. The question has provoked much argument among bacteriologists, who differ as to whether any or all pathogenic germs are destroyed. The point is an important one, and no doubt before long will be settled; but meantime, it is safer to assume that biological treatment does not destroy pathogenic germs.

EXPERIMENTS AT THE ACWORTH LEPER ASYLUM AT MATUNGA.

Sewage Farm.—Through the kindness of the Chairman of the Acworth Leper Asylum, the Author has been able in the last ten years to make some valuable experiments at the Asylum in regard to sewage disposal. The Asylum lies to the east of the ridge which runs north and south on the harbour side of the Island of Bombay and is about eight miles from the Fort. It is in such a position as prevents its being drained into the main sewerage system of the Island, except by pumping, and it has therefore its own separate system. In the early part of 1901, the Author published a short work, called *Notes on Sewage Disposal*, which dealt with various experiments made by him at the Asylum from the year 1894 up to that time.

It is now proposed to give a brief rèsumè of these experiments together with some further results. When the Asylum was constructed in 1891, it was a part of the Author's duty to supervise the drainage arrangements of the Institution. These arrangements consisted of stoneware pipe drains, laid from all *nahanis* and latrines so as to convey the sullage to two large pits filled with rubble stone and located on the outskirts of the Asylum; but owing to the presence of clay in the subsoil, these pits were unsatisfactory from the beginning and eventually became entirely choked with solid matter, so that the sewage overflowed on to the adjoining land not in the possession of the Asylum. This brought forward complaints from the adjoining land owners, who ultimately gave notice of their intention to apply for an injunction to prevent the Asylum authorities discharging sewage on to their land. This was in 1894, and arrangements were then made to purchase a tract of land adjoining the Asylum on which the sewage matter could be disposed. Originally, it was thought that it would be sufficient to dispose of the sewage in its crude state on this land, but this was found to be objectionable, as it resulted in a nuisance and in the land becoming coated with organic matter, which destroyed its purifying qualities. The fodder crops grown on the land were unwholesome and cattle would not eat them. It then became necessary to devise some means of purifying the sewage before discharging it on to the land. In 1895, the Author, working independently but curiously enough on the same lines as Mr. Cameron at Exeter, experimentally constructed the open Septic or Liquefying Tank shewn in Plate 44 and described more in detail later in this Chapter. It should be mentioned, however, that at this time the name "Septic Tank" had not been coined, nor had the properties and possibilities of such a tank been even approximately ascertained.

The land was at this time laid out as a small experimental Sewage Farm, in plots averaging about half an acre in area and so arranged as to be irrigated by the effluent from the Liquefying Tank. The channels or carriers for conveying the effluent were lined with half stoneware pipes of 9 inches and 6 inches diameter according to requirements. In 1895 the area was 3·63 acres, but with the extension of the Asylum, this has now been increased to 5·92 acres.

The natural soil of the Farm was of the least desirable character for cultivation purposes, being yellow clay overlying *muram* but by much ploughing, turning over, and irrigation it has been greatly improved, although still leaving very much to be desired. The level of the land on the Farm is such that only one-third of it can be irrigated by gravitation direct from the Liquefying Tank. For irrigation of the remainder, the sewage effluent is allowed to flow into wells, from which it is lifted by Persian wheels, bullocks being used as the motive power. During the dry weather, the whole of the daily sewage from the Asylum—upwards of 20,000 gallons—is discharged into the Liquefying Tank and afterwards disposed of on the Farm; but during the monsoon months, in periods of heavy rain, when water is not wanted for the crops, the effluent is allowed to flow away with the storm-water to the sea, it being then inoffensive and practically innocuous.

The crops chiefly grown on the Farm are guinea grass, maize, and jowar, with a rotation crop of some pulse or vegetable. Lucerne has been tried, but not with any very great success, the reason being that the plant obtains its nitrogen from the air by means of tubercles which settle on its roots. If the tubercles do not exist in the soil, the plant will not grow. English vegetables have been grown with considerable success, all attaining a large size. Six crops of maize and jowar are obtained in a year and a cutting of guinea grass once every month throughout the year.

The following figures represent the total returns of fodder grown on the Farm for the year 1904-5:—

Maize	37·54	tons.
Guinea Grass	36·71	"
Jowar	132·97	"
Vegetables	0·56	"
Mangel Wurzel	1·91	"
Lucerne	3·91	"
Total ...	213·60	tons.

As only 5 acres, on an average, were under cultivation during this year, this gives a total return of nearly 44 tons of fodder per acre for the year—a result which must be considered as very satisfactory. Nearly all this fodder has been supplied at market rates to the Health Officer of the City of Bombay for feeding the Health Department bullocks.

The labour on the Farm, except the supervising staff, consists to a large extent of lepers, who are paid a fair wage for the work they do. Their health is very greatly improved by the regular exercise thus obtained, but their strength is never equal to that of a healthy cooly.

The financial success of the Farm has been a progressive one. In 1899-1900 the net profit was equal to 21·92 per cent. on the capital outlay; while in 1900-1901 it reached 30 per cent. and in 1904-1905 45 per cent.

The following tabulation shews the progressive gross revenue and expenditure from 1895, when the Farm was first started, to 1905. Except for the first year, the Farm has always paid its way and furnishes an excellent example of the improvement that will take place in the

fertility of a poor land after some years of irrigation with sewage effluent:—

	Income.			Expenditure.		
	Rs.	A.	P.	Rs.	A.	P.
1895	158	7	10	509	12	1
1896	1,011	12	6	520	13	10
1897	1,722	2	1	570	8	6
1898	1,556	2	6	611	5	0
1899	3,781	12	9	1,057	10	5
1900	5,167	11	1	2,371	14	5
1901	7,073	6	11	3,972	8	0
1902	9,584	6	11	3,991	6	0
1903	6,978	3	0	3,930	12	0
1904	8,625	3	0	3,207	9	11
1905	8,513	9	10	3,464	6	8

During the eleven years that the Farm has been under irrigation, none of the plots have remained fallow for more than one month at a time. During 1901, some of the crops shewed signs of failing, and arrangements were then made to burn stable litter upon the ground spread to a depth of 1 foot, the ashes being dug in. This resulted in re-supplying the land with potash and phosphates and the necessary chemical bases, and since then quite abnormal crops have been obtained. This is the only sign of failure that has been observed during the time the Farm has been in existence.

Considerable doubt existed as to whether the irrigation of sugarcane by sewage effluent was likely to prove injurious to the plant, and the point has from time to time been freely discussed at Poona and elsewhere. Accordingly, in April 1901, a careful experiment was carried out, about 200 cuttings of sugarcane being planted in a small plot on the Farm. The trial was made with cane of the variety known in the Bombay Market as *surti*. The plot was irrigated solely with the effluent from the "Liquefying Tank," four or five times a month, for a period of nine months, no

manure of any other kind being applied to it. The crop was good and the outturn, when it was cut on the 27th January 1902, was 500 canes. This figure, however, does not represent the actual number of canes, for rats appeared to have taken a great liking to them, and, in spite of all precautions, at least 100 canes must have been destroyed by the time the crop was ready for cutting.

The juice was extracted in the ordinary way by crushing the canes between wooden rollers. It was at once boiled and converted into jaggery or "*goor*" by a man engaged in that particular trade, who was specially brought to the place for the work.

The total quantity of jaggery obtained was 3½ maunds. It was of a brown colour with a very sweet taste and crystallized and solidified properly.

A sample of the raw sugar was forwarded to Dr. J. Walter Leather, Agricultural Chemist to the Government of India, and the following is the analysis of it with his remarks:—

Cane-sugar	69·80
Glucose	13·65
Moisture and dirt	16·55
	100·00

"The sample contained a good deal of dirt, which might with "advantage have been screened from the juice before boiling. Other-"wise, it is a good raw sugar and better than much which is commonly "made by the cultivator."

(*Sd.*) J. WALTER LEATHER.

The result shews that sugarcane can be successfully grown under effluent irrigation and that the quality is at any rate as good as that ordinarily grown by the cultivators with the aid of the usual solid manures. This experiment

should be an encouragement to continue the growth of sugarcane in larger quantities under similar circumstances.

Mangel Wurzels were tried on the Farm during 1904 with some success, but the crop had a tendency to run to excessive leaf. This is also the experience with English vegetables. An interesting analysis was made by Dr. J. Walter Leather, in January 1905, of two samples of maize grown entirely with sewage effluent irrigation at the Sewage Farm. They were specially examined for the presence of a Glucoside named Bhurrim, sometimes met with in maize. The maize was declared to be quite free of any such noxious ingredient and was of a specially good quality for fodder purposes.

Liquefying Tank.—Plate 44 shews the installation of the open Liquefying Tank at Matunga, consisting of a series of four tanks, each 20 feet by 10 feet by 4 feet deep, connected with the other by an opening 12 inches wide in the dividing wall of the tank at the same level as the inlet to No. 1 tank. Each tank is further divided by a baffle wall for three-fourths of its length, which almost makes two compartments of it, round which the sewage flows. Each tank is fitted with a loosely adjusted scum board to reduce the surface velocity of the sewage. Any tank can be cut off from the others by means of wooden stops and closed for cleaning purposes. The whole of the four tanks working together have a total capacity of 3,020 cubic feet of 18,875 gallons, though, as deposit increases, this capacity correspondingly decreases. The surface sewage, when the tanks are fairly free of deposit, takes an average of eight hours to pass through the distance of 160 feet or at a velocity of 20 feet per hour. This average result was obtained by several float experiments after removing all the scum boards.

The velocity of sewage through a Liquefying Tank varies with the volume of sewage flowing into it, which is not a constant quantity, and it again varies as the capacity of the tank is reduced by deposit. The surface velocity must not be taken as the average velocity for the whole tank, as the ratio between the surface and average velocities varies according to the design of the Tank and the amount of deposit. Parallel to the Liquefying Tank and running the whole length is a sludge tank, connected to each compartment by means of a 9-inch pipe. The bottom of this sludge tank is two feet below the level of the bottom of the Liquefying Tank. When it is desired to clean any of the compartments of the Liquefying Tank, it is shut off from the others by closing the necessary stops in the channel; and the sewage and sludge are run into the low-level sludge tank through the 9-inch pipe connections. The sludge is then allowed to settle, the liquid being drawn off by a pump, and when the sludge has dried, it is removed and dug into the land, which it seems to considerably benefit, for although the dry sludge has no value as manure, it helps to lighten the soil. The sludge tank is only used—when it becomes necessary to clean out any of the compartments—at intervals of about three years.

The Asylum has been slightly enlarged since the Liquefying Tank was constructed, and upwards of 20,000 gallons of sewage are now passed through it per day and dealt with satisfactorily. The liquefaction of the solid matter in the sewage discharged into the tanks is very complete and over 80 per cent. of reduction in albuminoid ammonia is attained during the time the sewage is passing through them.

The population of the Asylum is now about 430 and the whole of the sewage finds its way by a regular system of pipes from the washing places, latrines, and dhobi-ground to the Liquefying Tank, except a small quantity

intercepted for experiment in a Ducat Filter. In the light of the present experience, the design of the tank is defective; and if it were necessary to now reconstruct it or to construct another, an altogether different design would be adopted and more suitable walls constructed with openings alternately at the top and the bottom. These tanks, however, have done the work required of them quite efficiently, and considering that they were constructed in the first instance purely for experiment in a then unknown direction, their success has been remarkable. A series of observations of the temperature of the air and of the sewage entering and leaving the tanks, taken over a period of nine months, shews that there is no difference in the temperature of the sewage entering or leaving the tanks and that the temperature of the sewage has no connection with the temperature of the outside air.

The following is the average of several analyses of the crude sewage at Matunga and of the effluent from the Liquefying Tank, made by the late Dr. C. H. Cayley, M.A., M.D. D.Ph., who was Divisional Health Officer, Bombay:—

Parts per 100,000.

	Total Solids.	Suspended Solids.	Chlorine.	Free Ammonia.	Albuminoid Ammonia.
Crude Sewage.	64·91	31·83	3·36	1·08	1·62
Tank Effluent.	30·96	8·80	3·35	1·11	0·311

This gives on an average a purification of the sewage equal to 81 per cent. as estimated on the albuminoid ammonia.

In the eleven years the tank has been working, it has been cleaned out on three occasions only, the first cleaning being after three years' use. It was calculated that up to that time the organic matter liquefied in the

tank amounted to 61 tons. In England, it is usually calculated that 50 per cent. of the solid matter deposited in a Liquefying Tank is disposed of; but the experience at Matunga is that at least 75 per cent. is liquefied.

The Author is indebted to Dr. J. Walter Leather, the Agricultural Chemist to the Government of India, for the following analysis of a portion of the solid matter removed in 1902 from the tank at the time of cleaning:—

"*Analysis made on 18th February, 1902.*

Moisture	65·18
Organic matter	9·74
Mineral matter	25·08
Total	100·00
Containing nitrogen	·56
Do. sand	13·08
Do. phosphoric acid	0·32

"This material appears to correspond closely in composition to "that which Dr. Rideal examined for the Exeter Septic Tank."

(Sd.) WALTER LEATHER,

Agricultural Chemist to the Government of India.

This is an interesting analysis and it will be noted that 72 per cent. of the solid matter, or humus as it is called, remaining in the tanks at the time of cleaning was mineral matter and therefore not further reducible by the bacteria. In average fæces the percentage of organic matter is 86 and mineral 14.

The inference to be drawn from the above is that an even warm temperature has much to do with the proportion or organic matter disposed of and left undisposed of, respectively, by the bacteria; for whereas 24 hours are stated to be required in England for the treatment of the sewage in Liquefying Tanks, the same work is more efficiently done here in Bombay in 8 hours, with a purely domestic sewage.

When it is necessary to clean out a Liquefying Tank, care should be taken to always leave a small amount of deposit in the bottom for the immediate renewal of liquefying action when the tank is put into operation again. The bacteria will no doubt develop in an absolutely clean tank, but it will take time for them to accumulate to the quantity requisite for the maximum degree of purification.

Too much stress cannot be laid on the fact that the surface or scum of the Liquefying Tank should not be disturbed, as interference with bacteria means a suspension of their work, and in places where heavy rains are frequent the tank should on this account be protected with a covering.

The following analyses of sewage taken at the point of discharge from No. 2 into No. 3 tank (see Plate 44) and of the final discharge from the tank four hours afterwards are very interesting, for the result shews that probably the greater part of the breaking down of the organic matter is done by the bacteria in No. 1 and No. 2 tanks, which is further borne out by the fact that in some respects the effluent from No. 4 tank is inferior to that from No. 2 tank:—

Parts per 100,000.

	Total Solids.	Suspended Solids.	Chlorine.	Free Ammonia.	Alb. Ammonia.
Crude sewage entering Liquefying Tank, 21st February, 1901 ...	64	16	4·00	2·64	·68
Sewage taken from point of discharge of No. 2 Tank, 10th May, 1901.	44	16	2·3	1·60	·448
Effluent taken from final discharge of Liquefying Tank, 10th May, 1901 ...	36	8	2·3	1·44	·608

The analysis of the crude sewage is given as a guide only, it having been made on a different date from that of the effluents, and is, as indicated by the chlorine, not of the same sewage. The point that it is desired to bring out is that, at any rate in India, the largest percentage of purification is carried out much more quickly than is generally supposed.

It has been proved by experiments in England that no purification advantage accrues from allowing sewage to remain in a Liquefying Tank for more than 24 hours and that it is far from being improved by remaining 48 hours.

The analyses made from time to time of the effluents taken from the different compartments of the Liquefying Tank at Matunga, after 4 hours, 6 hours, and 8 hours contact, respectively, go to shew that the maximum purification is obtained in a warm climate in much less time than in a climate such as that of England.

The average temperature of sewage in England is between 51° and 58° F., while in Bombay it is between 78° and 90° F.

From an average of analyses spread over two years, the Author has found that with a temperature of sewage at 83·60° F., 55% of the purification occurs in 4 hours, 82% in 6 hours, and 84% in 8 hours. It may, therefore, be assumed that, with a climate similar to that of Bombay, an 8 hours contact with ordinary domestic sewage will give a purification that will be satisfactory.

A word here may not be out of place in regard to the relative advantages of covered and uncovered Liquefying Tanks.

The word "covered" denotes that the tank is completely roofed. Two compartments of the Liquefying Tank

at Matunga are now covered for the purpose of generating and collecting the gas. Observations shew that with an air-tight roof on a Liquefying Tank, if the gas is not removed as it forms, purification is interfered with. Thus at Matunga, when only No. 1 compartment was covered, much of the purification which took place in that tank before it was covered was transferred to No. 2, and the same process is at present taking place in regard to No. 3, now that No. 2 is covered.

The opinion of the Author is that unless it is desired to make use of the generated gas, it is better to allow a tank to remain uncovered ; for, if a tank is scientifically constructed, no nuisance will arise from it after it has come into fair working condition.

Sewage that has been passed through a properly designed Liquefying Tank is so free from organic matter that, if it is subsequently dealt with by æration only, it rapidly becomes clear and free from smell.

In regard to the designing of a Liquefying Tank, it is desirable to point out that the size of a tank should always be calculated on the maximum flow of the sewage. It should, if possible, be three times as long as it is broad, and its depth should not exceed 6 feet, 5 feet being a preferable depth. The first object of a Liquefying Tank is to reduce the flow of sewage so that all solid matter may be deposited as quickly as possible. The position and construction therefore of baffle walls is a matter of considerable importance. It is very questionable whether the submerged inlet serves the useful purpose it is supposed to, for there is certainly less disturbance of the tank when the inlet is at the surface. However, no hard and fast rule can be laid down in this matter, as so much depends on the installation.

In small installations, the great difficulty is always the uncertain flow of sewage. It is therefore desirable to make

a Liquefying Tank for a small installation sufficiently large to counteract this difficulty.

Plate 45 shews a sketch for a proposed open Liquefying Tank for the sewerage of Ahmedabad. The tank is designed to deal with 1,200,000 gallons of sewage per diem. It consists of six compartments, two of which are each 200 feet long by 25 feet wide by 5 feet deep and the remaining four 150 feet long by 25 feet wide. The discharge of each tank is at the same level, over a weir.

Plate 46 shews a covered Liquefying Tank suitable for a small installation. Here the compartments are 11 feet long by 6 feet wide by 5 feet deep, and the passage through the tank is alternately at the top and the bottom of the different partition walls. The roof is constructed of some light gauge galvanized iron and fixed on angle iron ribs with a manhole at one end for inspection purposes. The withdrawal of the gas from this tank might be at any convenient point by means of a pipe let into the roof.

Plate 47 shews a Liquefying Tank with a filter attached—an installation which was designed for the purification of the sewage of a large bungalow in Bombay. This installation has been working for a considerable time satisfactorily. Here it will be noticed that the roof of the tank has been provided with an opening covered with wire gauze, as it was not intended to make any use of the gas. The description of this class of filter will be dealt with later in the Chapter. Plate 48 shews a drawing of a covered Liquefying Tank.

Filters.—Various filters have been constructed at Matunga, combined with the liquefying and other tanks, and fitted with different arrangements for distributing sewage on to their surfaces, and also with several different materials as filtering media. Experiments have been tried with a Liquefying Tank combined with Ærobic Filters, and

with a Liquefying Tank combined with a Contact Filter, and with a Macerating Tank combined with Colonel Ducat's Filters.

A Stoddart Filter with a patent "distributor" combined with a Macerating Tank and a Colonel Ducat's Side Ærated Filter dealing with crude sewage only have also been tried. More recently a series of two Contact beds fitted with Adam's Timed Siphons have been erected to deal with the Liquefying Tank effluent, as also a Streaming Filter fitted with an Adam's Rotating Distributor.

All these filters, tanks, and modes of distribution of sewage on to filters, many of which are new and interesting, are fully described and commented upon in the following pages.

Attached to the Liquefying Tank, shewn in Plate 49, are two small Ærobic Filters, 2 feet 6 inches by 2 feet 6 inches by 2 feet 6 inches, built entirely for experimental purposes. These filters are designed to receive and to purify the effluent from the Liquefying Tank at the rate of 250 gallons per square yard per day. The medium used for filtering is in one case burnt brick, broken from 1/8th inch to 1-inch cube, and in the other, English coal also broken to the same sizes.

In the brick filter, the effluent from the Tank is delivered by three galvanised distributing pipes under a head of 7 inches and having 1/16th inch perforations at intervals of 5 inches. These distributing pipes work fairly well, in spite of the fact that some of the perforations are occasionally closed by floating solid matter. In the coal filter the Tank effluent is distributed by small tipping troughs, which, when full, tip automatically one way and empty their contents on to the filters. This kind of distribution is apt to disturb and ridge the top of the filtering medium, especially if it is of fine material. The time of the passage of the effluent through both filters is exactly the same, being from 10 to 12 minutes, and the resultant effluent shews a very high degree of purification, and is in appear-

ance like the purest spring water—bright, clear, and free from all deposit and smell.

The following are the two analyses of the effluents from each filter made by Dr. C. H. Cayley in February 1901 and in July 1902:—

Parts per 100,000.

Filter.	Total Solids.	Chlorine.	Free Ammonia.	Alb. Ammonia.	Nitrites.	Nitrates.
Burnt brick effluent taken February 1901	29·33	3·63	0·340	0·106	0·343	3·84
Burnt brick effluent taken July 1902 ...	32·85	2·7	0·024	0·042	*Nil.*	11·70
English coal effluent taken February 1901	20·00	3·20	0·172	0·065	0·201	6·35
English coal effluent taken July 1902 ...	22·85	2·4	0·010	0·027	Trace.	2·214

The analyses are interesting and shew that the efficiency of each filter has been quite maintained during the eighteen months that had elapsed since the first analyses were made.

They have been continuously worked without cleaning or being in any way interfered with since their construction in January 1901. The percentage of purification over the crude sewage admitted to the Liquefying Tank is over 90 per cent., and the time taken in the operation is eight hours in the Liquefying Tank and twelve minutes in the filters.

Dr. Cayley remarks in regard to the two later analyses that "the effluents were clear and bright with a small trace of a brownish sediment" and that "the sewage was weak." This latter may be accounted for by the fact that either the sewage was night sewage, which is always weaker than day sewage, or that there had been rain during the

night, which diluted the sewage flowing into the Liquefying Tank, for although the Asylum is drained on the "separate" system, some rain water gets into the sewers through the washing places. Such a high degree of purification as is shewn by the above analyses is not necessary for an effluent of sewage farming in India, and the amount of purification obtained from a scientifically constructed Liquefying Tank without further filtering is all that is required, as the land converts the organic matters into those which are necessary for the life of plants and very quickly does what the filters would do, leaving the effluent in such a degree of purity that it may with safety be allowed to flow where it will.

Neither of the two materials used in these filters for filtering purposes has degraded to any large extent, nor has any choking of the filters ensued. Of the two materials, English coal gives the better result, and this has also been noticed in England, but no satisfactory explanation has been forthcoming.

Fig. 32 shews a small filter for upward filtration designed by the late Mr. W. Santo Crimp, M.Inst. C.E., and

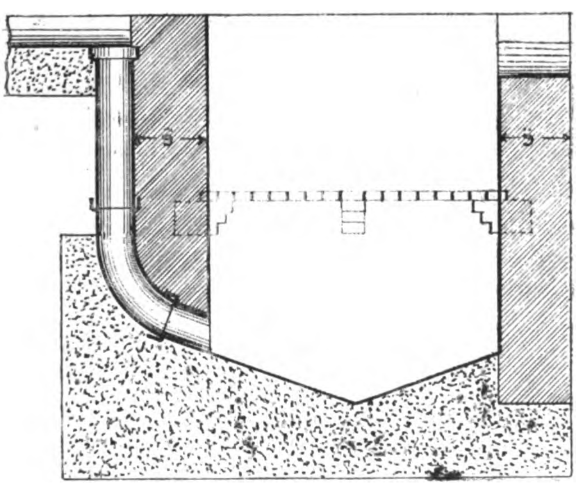


FIG. 32.

called a "Macerating Tank." Sewage is admitted at the bottom of the tank and passes upward through a layer of one foot or more of road metal. The solid matter is retained in the bottom and is no doubt there disposed of by anaerobic bacteria as in a Liquefying Tank. When cleaning is necessary, the sewage is passed through the road metal or filtering material the reverse way and the deposit flushed out through a sluice provided for this purpose. This class of tank is useful chiefly for arresting the solids in the sewage, but its purifying properties are slight, as it is constructed of a small size, compared with a Liquefying Tank.

Adjoining the Macerating Tank and combined with it is a filter 6 feet by 3 feet by 3 feet deep, shewn in Fig. 33, worked on the principle of a Contact Filter. This filter receives sewage after it has passed through the Macerating Tank, so that it arrives free of solid matter to a large extent. The filtering medium used is coal clinker all broken evenly to

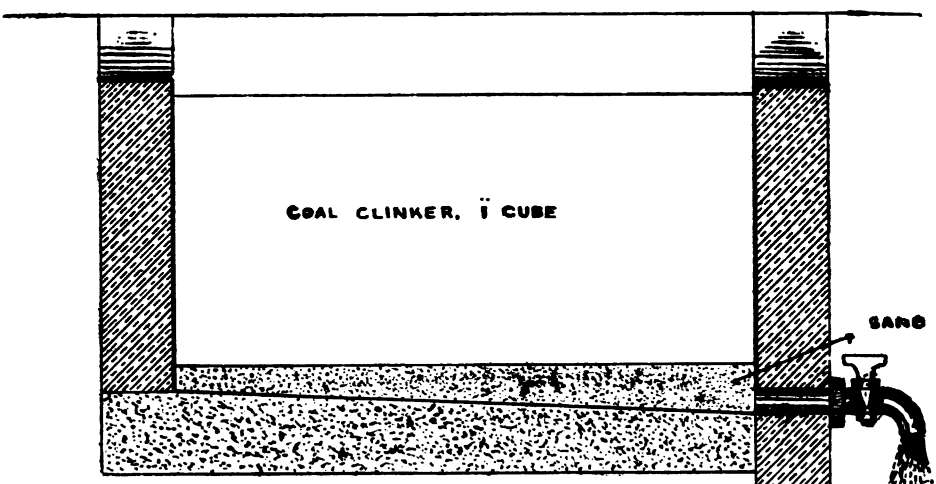


FIG. 33.

one inch cube. Originally, three inches of river sand at the bottom was tried, but this was found to be useless as it was gradually all washed out with the effluent.

This filter is worked in cycles of eight hours, that is to say, it is filled in two hours, rests full for two hours, is emptied in two hours and rests empty for two hours. Sewage at the rate of 250 gallons per square yard per day is passed on to the filter, and analyses shew that the purification obtained is 80 per cent. or about the same as with the Liquefying Tank. This must be considered satisfactory, as the sewage, which has had practically no previous purification, is only in actual contact with the filtering material for an average of four hours. In England, filters of this description are frequently built in a series of two so as to provide for two contacts, and sometimes three contacts are considered to be necessary to obtain a satisfactory degree of purification.

When the filter was constructed in October 1899, its sewage capacity after careful measurement was found to be 41 per cent. of its total cubical capacity. It was again measured some two months afterwards and found to have been reduced to 33 per cent. In July 1902, that is 31 months later, all the contents of the tank were removed, measured, washed, and put back again, and it was found that the capacity had been further reduced to 31 per cent. or by 2 per cent. only in 31 months, and there was no degradation of the clinker filtering material. This is a very interesting result, because one of the apparently insurmountable difficulties with this class of filter in England at present is the rapidity with which it sludges up, and the cost of constantly cleaning such a filter of large area is a very serious item in the expense of a biological installation. There is no doubt that the Macerating Tank which retained the greater part of the solids in suspension helped largely to the good result obtained at Matunga, and it goes to shew that this kind of filter can be worked without serious sludging up for a considerable period, if, in some way, the greater part of the solids in the sewage are

arrested and not passed on to the filter. If the degree of purification attained after passage through this filter were insufficient under any particular circumstances, the additional purification desired could be attained by further filtration through a second or even a third similar filter.

Combined also with the filter above described is a small covered Liquefying Tank, constructed of lime concrete, the internal dimensions of which are 5 feet by 4 feet by 3 feet. This Liquefying Tank is worked under similar conditions to the open Liquefying Tank and supplies the Contact Filter with effluent alternately with the Macerating Tank. It was worked continuously for eighteen months (July 1902), and the results obtained are on a par with those with the open Liquefying Tank, the analysis shewing a purification of 81 per cent. This result agrees with the experiments made with covered and open Liquefying Tanks in England.

Three continuous Ærobic Filters on Colonel Ducat's principle have been erected at Matunga. For descriptive purposes these filters are numbered 1, 2, and 3, the first having now been working continuously from two to six years and the latter two working for three years up to 1902. The special feature of a Ducat's Filter are (1) the side æration, by which air is passed into the body of the filter for the supposed better development of the ærobic bacteria, and (2) the direct reception of crude sewage without any previous treatment.

Plate 50 gives a drawing of No. 1 Filter, which is 5 feet by 5 feet by 8 feet deep or nearly three square yards in area, which, at 250 gallons of sewage per square yard, is capable of dealing with 750 gallons per day. The filter is supplied with sewage obtained from a bathing place and a latrine, used only by a colony of eighteen sweepers attached to the Asylum. Early in 1902, a water meter was fixed on the supply pipe, which shewed that the sweepers were

using 40 gallons of water per head per day or 720 gallons in all, so that the filter was then getting its full complement of sewage. The water-supply has since then been reduced to 10 gallons per head per day and the comparative analyses of the effluents will be given later on.

This side æration of this filter is much less than arranged for in Colonel Ducat's Standard Absaf Filter, where the walls are honeycombed with pipes. At alternate heights of one foot, pipes with butt joints are laid crossways through the filter, the joints of the pipes being about $\frac{3}{4}$-inch apart and meeting the pipes in the wall to enable the outside air to pass freely into the centre of the filter.

The filtering medium used is "overburnt brick," broken from $\frac{1}{8}$ inch to 1 inch cube, the smallest being at the top. This material is too fine for a filter dealing with crude sewage only; and though the ultimate results have been satisfactory, it is advisable to always have the top layer, at any rate, of coarser material, so that the solid excreta, etc., may be the sooner disposed of and also that the sewage discharged on to the filter may not "head up," as has here been the case on several occasions. The sewage is discharged on to the filter by means of tipping troughs as shewn in Plate 42.

These tipping troughs are automatic, and are balanced and hung in grooves, which require to be kept well lubricated. They tip alternate ways and empty as soon as they fill by overbalancing. They are satisfactory, except for the objection before stated, that with fine filtering material as a top layer they ridge that material in front of the discharge from the tippers.

The filter has, during the six years of its existence, given uniformly satisfactory results. Only three times during that period has the top foot of the filtering material

been removed and washed. It was then found by measurement that the degradation of the burnt brick had amounted to 50 per cent. of its original bulk, and this is an undoubted defect in this class of filtering material.

The following analyses of crude sewage and of the effluent taken in December 1900 and in July 1902 shew the purification obtained in the 45 minutes which the sewage takes to travel through the filter:—

Parts per 100,000.

	Total Solids.	Susp. Solids.	Chlorine.	Free Ammonia.	Alb. Ammonia.	Nitrites.	Nitrates.
Crude Sewage, December 1900 ...	380·67	310·67	5·73	2·531	1·253	*Nil.*	*Nil.*
Effluent, December 1900, 240 gallons per square yard ...	54·67	*Nil.*	5·367	0·077	0·067	0·625	13·555
Effluent, July 1902, 60 gallons per square yard ...	·85	*Nil.*	3·85	0·064	0·034	Trace.	28·8

The effluent in both cases was exceedingly bright and clear and free from any smell, and shewed that a very large amount of purification had taken place and that there was also very little free ammonia, practically the whole of the nitrogenous matter having been purified into nitrates.

That the filter has maintained its purification properties the July effluent undoubtedly shews.

The experiments made at Leeds under the supervision of the Royal Commission on Sewage Disposal prove that side æration is not necessary in a Continuous Filter, provided the surface of the material is kept open and clean, and that there is practically no difference in the purification obtained in an ærated and a non-ærated filter. Such æration is always from the top, the air naturally following

the sewage into the filter. As an example of the bacterial efficiency of this filter, it may be stated that a large dead rat was placed in the filter on one occasion and covered with about one inch of filtering material, and when examined four days afterwards, the whole of the rat had been broken up by the bacteria and had disappeared, leaving but a few fragments.

The success of this filter has been quite phenomenal. In the light of present knowledge, the filter has been, so far as its filtering medium is concerned, wrongly constructed, that is to say, the upper layer of the material is fine while it should have been coarse, and the lower part is coarse while it should have been fine. Again, nothing but crude sewage is discharged on to the filter, and on any morning lumps of excreta can be seen on its surface. Yet, with those disadvantages, the average of the analyses for absorbed oxygen taken every week for nearly twelve months gives 0·16 per 100,000 parts. The absorbed oxygen has never exceeded during that time 0·23, and on one occasion it dropped as low as 0·05 per 100,000 parts.

The effluent has been uniformly bright and sparkling, in a way that no other filter at Matunga has ever attained.

The filter has now been working for more than six years without intermission, and beyond the occasional removal of the first foot of the filtering material, nothing has been done to it during that time.

Filters Nos. 2 and 3 have been constructed alongside each other as shewn in Plate 51, and each measures 5 feet by 3 feet by 5 feet in depth, or 3 feet less in depth than the minimum recommended by Colonel Ducat. The sewage supplied to them is obtained from a latrine and a bathing place, erected solely for the use of one of the wards containing 24 adults. It first passes through a small Macerating Tank, 2 feet by 2 feet by 3 feet in depth, and is then discharged on to the filters. The filtering medium used in

No. 2 filter is burnt brick broken into from ½ inch to ¼ inch cubes, and that in No. 3 is English coal broken to the same size. For months, the effluents from both filters were turbid and cloudy, but in time they gradually cleared and were then for some months uniformly bright and clear. These two filters were in continual use for nearly three years, and the result shews that the depth of the filter of Colonel Ducat's design may quite well be less than the eight feet stipulated by him, and that with only five feet of filtering material a very satisfactory effluent can also be obtained. It must be noted, however, in regard to these two filters that sewage is first passed through a Macerating Tank, where most of the solids in suspension are arrested, though no particular purification takes place.

The following analyses made by the late Dr. Cayley in July 1902 shews that the quality of the effluents is exceedingly good: a comparison with No. 1 filter can hardly be fair, as that receives crude sewage:—

Parts per 100,000.

	Total Solids.	Chlorine.	Free Ammonia.	Alb. Ammonia.	Nitrites.	Nitrates.
No. 2 Filter, Brick ...	65·7	4·64	0·077	0·124	*Nil.*	31·00
No. 3 Filter, Coal... ...	70·0	4·86	0·009	0·045	*Nil.*	39·857

Both effluents were bright and clear and free from any smell and deposit. It will be noticed that the result obtained from the coal-filtering medium is again superior to that from the brick, the sewage in each case being the same and supplied at the same time.

Two samples of effluents taken on 10th March, 1901, and kept in stoppered bottles until July, 1902, retained their clearness and brightness without smell of any kind, shew-

ing that the purification was complete and that there was no secondary putrefaction.

The results obtained at Matunga with Colonel Ducat's filters have been uniformly good; but in any installations built in the neighbourhood of dwellings, it is desirable to give the sewage some previous treatment, for the reasons that an open filter receiving crude sewage must always be slightly offensive, as fæcal matter is likely to lie on the surface for some hours before being entirely broken up. Matunga has been more fortunate with a Ducat Filter than Leeds, where the discharge of crude manufacturing sewage on to a similar filter was found to be a distinct failure, though, when worked with a Liquefying Tank effluent, the result was more favourable. Temperature and the class of sewage are probably responsible for the better result here. For England, Colonel Ducat has specified that the sewage should be heated before being delivered into the filter, but that process, whatever its advantage may be in England, is certainly not necessary in India.

After the experiments carried out with Continuous Filters in England, side æration cannot be considered a necessary or even a desirable feature in a filter, therefore that special peculiarity of the Ducat filter may be dismissed. Again, the two filters above described shew, as already pointed out, that Colonel Ducat's minimum depth of eight feet is more than is necessary. This is very important, as a loss of eight feet in head is far more often impossible to afford without pumping than that of five feet The 8-foot filter has undoubtedly purified crude sewage very satisfactorily, but probably in India any Continuous Filter scientifically constructed would do the same.

Early in 1902 it became necessary to make arrangements for the drainage of a large Sanitarium in an unsewered district in Bombay and the arrangement shewn in Plate 52 was carried out. This installation provides for

all the sewage of the establishment being brought to a point and discharged into two Macerating Tanks, each 10 feet square and 4 feet deep. The tanks are placed side by side, so that they can be worked together or alternately, one being in use, while the other is being cleaned or kept in reserve. The lowest point of each Macerating Tank is connected by means of a sluice and a 9-inch pipe to a sludge tank for cleaning purposes. The sewage from the Sanitarium flows in at the bottom of the Macerating Tank and filters upwards through fourteen inches of road metal, the level of which is raised slightly higher than the weir connection with the open drain which leads to the filters, thus avoiding room for the growth of mosquitoes in the standing sewage. The filters are three in number and are constructed in a similar manner to Colonel Ducat's Absaf Filter. Each of them is 25 feet by 8 feet by 6 feet in depth: the sides are of concrete, honeycombed with 3-inch stoneware pipes, spaced about 3 inches apart: the outer ends of these pipes are at a higher level than the inner, the slope being to guard against the fluid passing out from the sides of the filter. Longitudinal and lateral pipes with open joints run right through the filter for the promotion of æration, and these are spaced about 2 feet 4 inches apart horizontally and 1 foot 5 inches vertically.

The filtering material is entirely clinker, varying from ¾ inch at the top to ½ inch at the bottom. The sewage is discharged on to tipping troughs from open channels running at right angles to them. The troughs are of the same kind as those described for the Ducat Filters at Matunga and are fixed 1 foot 9 inches apart from centre to centre, each trough running the full width of the filter, and the sides of each trough are 3 inches apart at the top.

The installation is designed to completely dispose of the solid and fluid matter from 36 water-closets, the sullage from 50 *nahanis* and all the waste water from the cook-

rooms. The effluent from the filters discharges into an ornamental tank surrounded by ferns, in which gold fish thrive, and the effluent can be used without any offensive smell for gardening purposes. The Sanitarium was constructed to accommodate 200 people, but that number has been often largely exceeded.

This installation is in a residential part of the town, and the Sanitarium is almost always fully occupied.

The following analyses of the crude sewage and of the effluent made by the late Dr. Cayley shew how exceedingly satisfactory the purification is:—

	Crude Sewage.	Effluent.	Proportion.
Free Ammonia	17·32	0·2	Parts per million.
Alb. Ammonia	5·44	0·28	Do.
Chlorine	3·2	4·9	Grains per gallon.
Total solids	59·00	47·0	Do.
Dissolved solids	36·00	......	Do.
Suspended solids	23·00	......	Do.
Nitrites	*Nil*	·126	Parts per 100,000.
Nitrates	*Nil*	4·5	Do.

" A very good effluent. Most of the organic matter has been converted into nitrates."

The effluent for this analysis was taken 35 minutes after the crude sewage, but it is evident that the effluent is one of a stronger sewage. The result is eminently satisfactory, and with the experience gained at Matunga there is no reason to suppose that the installation will not always continue to work well.

Up to the end of 1905 the installation has given universally good results. Analyses made from time to time

shew that the absorbed oxygen varies little from 0·20 per 100,000, which is an exceedingly good result. Occasionally, the Macerating Tank has been cleaned, but not oftener than once in six months. This is undoubtedly the disadvantage of the installation and the Author cannot recommend such a combination. A Liquefying Tank takes more room, but purification is done with little or no nuisance to the neighbourhood, while with a Macerating Tank there soon comes a time when it is overcharged with organic matter and a nuisance results, and there is a further nuisance when all the materials of the tank have to be removed for cleaning purposes. The filters have always been satisfactory, but the construction of the Macerating Tank has been an undoubted defect in the installation.

Continuous Filter fitted with Stoddart's Distributors.—Adjoining the two 5-foot Ducat Filters shewn on Plate 53 and sharing the same sewage with them, has been erected another filter, 5 feet by 5 feet by 4 feet deep. The special feature of this filter is its "Distributor," which was first designed by Mr. F. Wallis Stoddart, F.I.C., F.C.S., Public Analyst for Bristol; but in other ways it is just an ordinary continuous filter with closed sides. It is not a filter on to which it would be satisfactory to discharge crude sewage: such sewage should either be closely screened or passed through some previous treatment before it could with success be applied to a "Stoddart's Distributor." Several of these filters have been working near Bristol for a considerable time, with, it is stated, quite satisfactory results.

Plate 53 shews the patent "Distributor;" it is made of thin galvanized iron and consists of a number of narrow gutters arranged at right angles to the supply channel, and rests upon its margin and upon a suitable support at the other end. The level of the "Distributor" is so arranged that the sewage from the channel

flows equally into all the gutters. In these gutters there are a series of holes in which nails are loosely inserted. Besides these nail-holes, slots are cut in the top of the corrugations of the gutters. The sewage fills the gutters until it overflows through the slots, and, passing along the undersides, drips continuously from the nail points on to the filter, like rain.

The "Distributors" are made in sections, 8 feet long by 1 foot 6 inches in width, and are placed about 9 inches apart on the filters and 3 inches above the filtering medium.

The "Distributors" work by gravitation and require no head. This filter has closed sides and the filtering medium is burnt brick, broken to ¾ inch cube. It is combined with a Macerating Tank as are the Ducat Filters Nos. 2 and 3, and it has been working more or less continuously for twelve months, but still the effluent has been turbid and unsatisfactory.

The following is the analysis of an effluent made by the late Dr. Cayley in July 1902, when the filter had been in use for twelve months:—

Parts per 100,000.

	Total Solids.	Chlorine.	Free Ammonia.	Alb. Ammonia.	Nitrites.	Nitrates.
Stoddart's Filter	57·1	4·57	1·15	0·56	·736	1·77

The late Dr. Cayley says:—"The effluent was thick, "dirty-looking, and had a bad smell. There was a considerable amount of suspended organic matter, *i.e.*, un-"converted sewage, equalling 9 grs. per gallon. The free "ammonia was enormously high, the figures above being "only approximate, as the amount was too great to allow of "a proper test. Very little nitrification has taken place.

"This is a very bad effluent. This effluent was evidently "in a high state of putrefaction and continued to decom- "pose after 24 hours in a bottle."

There is therefore little real purification in this effluent, a reduction of the solids being apparently all that has so far been achieved.

Another analysis made by the late Dr. Cayley, on 2nd October, 1902, shews very little improvement on the previous one. In this instance, crude sewage as well as the effluent from the filter was analysed:—

	Crude Sewage	Effluent.	Proportion.
Free Ammonia	10·640	13·320	Parts per million.
Alb. Ammonia	5·2	3·540	Do.
Chlorine	3·3	3·4	Grains per gallon.
Total Solids	74	38	Do.
Dissolved Solids	32	......	Do.
Suspended Solids... ...	15	......	Do.
Nitrites	*Nil*	Trace.	Parts per 100,000
Nitrates	*Nil*	0·9	Do.

"A very poor effluent, containing some solid fæcal matter, as well as being thick and having a strong smell."

There is little improvement in the effluent during the three months interval between the two analyses; and, besides the reasons previously given, it is possible that the less depth of the filtering material—this filter being only 4 feet in depth and the Ducat's Filter alongside being 5 feet—had something to do with the continuous indifferent results obtained.

It is also more than probable in a filter receiving sewage, as this does, that the covering up with plates of a considerable area of the surface of the material and the delivery of the sewage from the nails on to exactly the same spot day by day, may have something to do with the poor results obtained. Whatever may be the reason, the fact remains that after fifteen months' trial the effluent leaving the filter is still in a putrefactive condition.

It will be kept in view that the sewage supplied to the two 5-foot Ducat Filters and the Stoddart's Filter was exactly the same, being supplied from the same channel with branches to the different filters.

With the high temperature in this country, a filter should be in full working order in a month, provided the sewage has some previous anærobic treatment; but if sewage is only screened or passed through a Macerating Tank, the probability is that it will be some months before it gives a satisfactory effluent.

An interesting experiment was made with the Stoddart and Ducat Filters by removing the Stoddart Distributors from the former and placing them on the latter, and removing the tippers from the latter and placing them on the former. This experiment resulted in an almost immediate improvement in the Stoddart Filter effluent and a corresponding decrease of purification in the Ducat Filter effluent, which had been previously universally bright for many months and almost immediately commenced to shew signs of opalescence.

On the 26th of October, 1902, Mr. G. Midgley Taylor, M.I.C.E., F.C.S., made an estimate of the oxygen absorbed by the sewage entering the Ducat and Stoddart Filters, and by the effluents discharged from each of them, with the following results:—

Parts per 100,000.

Crude sewage	... 1·12,	oxygen absorbed in 4 hours.
Effluent from the Stoddart Filter	... 0·70	,, ,, ,, ,,
,, ,, Ducat Filter	... 0·12	,, ,, ,, ,,

This confirms the strong probability previously mentioned, that the covering of the surface of the filter, built with closed sides, with plates, of the description of a Stoddart Distributor, is deleterious to the working of the filter, and tends to prevent air passing into the filter from the surface, which is a necessity in a filter of this description. The previous analysis of the effluent of the Stoddart

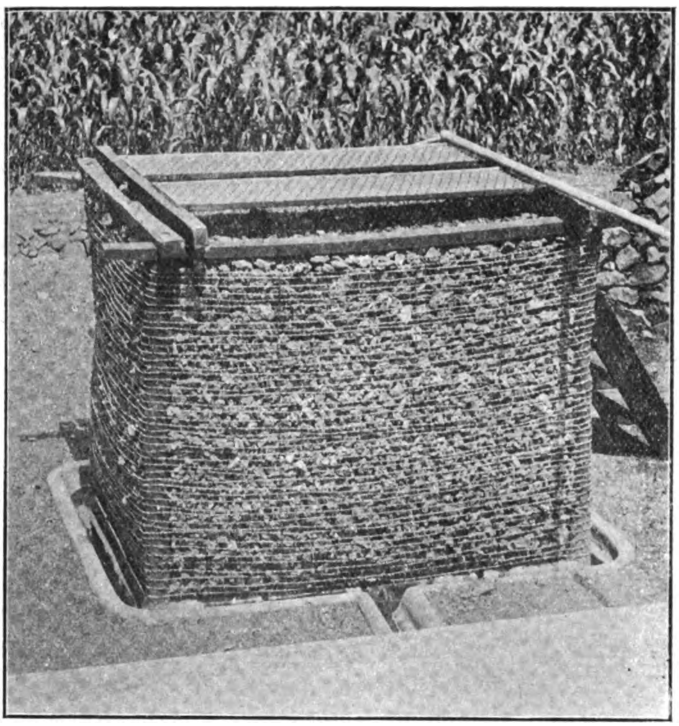


FIG. 34.

Filter made by Dr. Cayley shewed that effluent to be in an advanced state of putrefaction : the latter result therefore is a great improvement in purification.

The above results with a Stoddart's Filter are not as satisfactory as they should be. In 1903, the Author had the pleasure of meeting Mr. Stoddart at Bristol and also the

opportunity of inspecting his filters at Horfield, and certainly the results obtained there were at that time very much in advance of anything obtained at Matunga. Having this in view, the Author decided early in 1904 to construct a new Stoddart's Filter on somewhat different lines.

A filter was therefore constructed 7 feet by 6 feet by 6 feet deep. A photograph of this is shewn in Fig. 34. The filter is constructed on a sloped concrete base with four posts built into the concrete at the corners and the whole surrounded by wire to support the filtering medium, which in this instance is coal clinker of the best quality, carefully washed before being placed in position.

The effluent from the Liquefying Tank is pumped direct to the Stoddart Distributors. Regular weekly analyses for absorbed oxygen, taken from July 1904 to August 1905, shew that at an average temperature of 81° F., the absorbed oxygen was 0·326 per 100,000 parts, while that for the effluent from the Liquefying Tank was 0·921.

After the first week, the analysis shewed that the absorbed oxygen in four hours per 100,000 parts was 0·57. After seven weeks working, this dropped down to 0·30, which was a fairly satisfactory result. This result was maintained with slight variations both ways until the end of August 1905. The effluent takes about fifteen minutes to run through the filter and the average percentage of purification obtained in that time is 65. There is little doubt that a Stoddart Filter built under the conditions shewn in the above photograph should be successful, and nothing can be more simple and economical in construction.

The filter has required practically no attention and has shewn no signs of deterioration.

In September 1902, the Author constructed at Matunga a circular filter, which is called a "Streaming Filter." The sides of this filter are constructed of dry brick supported at four places by dry rubble stone buttresses.

The filter is 12 feet in diameter by 7 feet in height. The filtering medium is coal clinker, of uneven size from 2 to 3 inches. Effluent from the Liquefying Tank is distributed on to the filter by one of Adams' Patent "Rotating Distributors."

This distributor consists of a bucket rotating on ball bearings and fitted with radial arms of ¾-inch galvanized pipes perforated with holes every five inches. These noles are made only on one side of the pipe and in opposite directions to one another, the pressure of the water on the sides opposite to the holes forcing the arms to revolve. The apparatus can be worked with two or more arms according to the flow of sewage.

The radial arms depend for their velocity upon the head of liquid and angle of delivery; and by depressing the arms the number of revolutions can be increased.

If it is desired to sluice the filter out, the arms should be depressed and the flow of sewage increased to such an extent that in a short time the filter is cleansed of its solid matter. This is a very satisfactory way of cleansing the filter and is obviously more economical than removing all the material and washing it.

The amount of material remaining in the filter is, however, small, as filters worked on this principle eject a certain amount of the solid matters along with the effluent. The solid matters thus ejected are quite innocuous and readily settle, leaving the liquid effluent brilliant and clear.

The Liquefying Tank effluent takes about fifteen minutes to pass through the filter: the radial arms thoroughly distribute it over the surface of the filter, and the discharge at the bottom is equal at all points.

The following are the three analyses, made in 1902, by the late Dr. Cayley, of the Crude Sewage, the effluent from the Liquefying Tank, and the effluent from the Streaming Filter, the latter being after the Streaming Filter had been

in work for a fortnight. This Dr. Cayley describes as having a slight milky appearance, faint brownish tinge, trace of sediment, and slight earthy smell:—

	Crude Sewage.	Effluent from Liquefying Tank.	Effluent from Streaming Filter.	Proportion.
Free Ammonia	11·300	9·408	3·040	Parts per million
Alb. Ammonia	26·450	2·520	1·480	Do.
Total Solids	102·00	23·00	18·00	Grains per gallon.
Suspended Solids.........	53·00	3·00	...	Do.
Chlorine	3·6	2·4	2·1	Do.
Nitrites as NO_2	...	...	1·314	Parts per 100,000
Nitrates—				
as N........................	...	...	0·35	
as NO_3	...	...	1·55	

This effluent, although the Streaming Filter had then worked for only fifteen days, is nearly as good as that obtained from the Double Contact Beds, hereinafter described.

That the effluent has improved since the analysis was made by Dr. Cayley there is no doubt. It is much clearer in appearance, and an estimation made by Mr. G. Midgley Taylor, M.I.C.E., F.C.S., of the oxygen absorbed in four hours, on the 26th October, 1902—twelve days after the analysis made by Dr. Cayley—shews it to be a first class effluent. A sample of the Liquefying Tank effluent taken from the radial arms, and fifteen minutes afterwards a sample of the effluent from the filter, gave the following results:—

Parts per 100,000.

Liquefying Tank effluent	0·59	Oxygen absorbed in 4 hours.
Streaming Filter effluent	0·07	

Taking into consideration the fact that the Streaming Filter had been then in use for only about a month, the above results cannot be considered otherwise than exceedingly satisfactory.

Since the above date, the filter has continued to work for several hours every day and is still (1906) working.

Regular weekly analyses have been taken for absorbed oxygen, and the result has been uniformly good. The highest record of the absorbed oxygen was 0·34 per 100,000 parts and the lowest was 0·07, while the average for a period of one year was 0·21—a satisfactory result. Liquefying Tank effluent at the rate of 440 gallons per square yard per diem, equal to nearly 2,000,000 gallons per acre, is passed through this filter.

The filter is very simple in construction and has required no kind of attention. The rotating distributors work easily under a head of one foot six inches. Beyond the fact that the ball bearings require to be lubricated and the orifices in the arms to be occasionally cleansed, the apparatus needs no particular supervision, and undoubtedly this class of filter has a great future before it.

Contact Beds.—Contact beds are so called because sewage remains in them in contact with the filtering material for some length of time. As is described hereinafter in this Chapter, the effluent from the Liquefying Tank at Matunga flows by gravitation from a raised iron tank on to a series of two contact beds through a 2-inch pipe.

Before discharging on to No. 1 bed, the effluent from the Liquefying Tank is discharged into a measuring tank as shewn on Plate 54. This measuring tank holds, when full, 2,500 gallons of effluent—the exact quantity required to fill each contact bed in turn, and has a recorder which registers its discharges. It is fitted with a siphon, which automatically discharges the contents of the tank when the latter is full.

The size of each contact bed is 30 feet by 17 feet by 3 feet 4 inches of useful depth. In each bed a small chamber is partitioned off at the outlet side of the bed by three masonry walls in which an Adams' Automatic Timed Siphon is placed. The over-draw arm of the siphon goes through one of the partition walls and dips into the liquid contents of the bed, the inlet to the arm being protected by a perforated half-round galvanized iron sheet. A small bent pipe is placed at the side of the siphon, one end dipping into the small chamber and the other into the liquid contents of the bed. When the latter is full, the pipe begins to lead the effluent from the bed into the small chamber, the rate of flow being regulated by a stop-tap fixed on the pipe in the chamber. When the chamber is filled to a certain height, the siphonic action comes into play, discharging the whole of the contents of No. 1 bed into No. 2. The duration of contact thus depends on the time the chamber takes to be filled to the requisite height, which is, as stated above, regulated by the stop-tap. The same procedure then takes place in the No. 2 bed as in No. 1, the final discharge from it being into an open channel communicating with the main channel, which empties itself into two of the wells on the sewage farm. The filtering medium used in both the beds is coal clinker, that in No. 1 being broken to pass through a screen with 1-inch meshes and that in No. 2 through one with $\frac{3}{4}$-inch meshes.

The following has been the cycle in vogue for the filling and the emptying of the contact beds during 24 hours: No. 1 contact bed commences its contact at 9 A.M. each morning, and remains so until 11 A.M., when it automatically discharges into No. 2 bed—a proceeding which takes exactly 30 minutes. No. 2 bed is then in contact until 1-30 P.M., and is finally emptied by 2 P.M., Both beds then remain empty until 5 P.M., when No. 1 fills again and is in contact until 7 P.M. It then automatically discharges into No. 2 bed, and the same procedure

as in the morning takes place, No. 2 bed being finally emptied at 10 P.M., after which both the beds remain empty until 9 A.M., the next morning, so that in the 24 hours each bed rests empty for 5½ hours after the first contact and 13½ hours after the second contact.

The contact beds commenced working with the effluent from the Liquefying Tank on the 15th of September, 1902, from which date until the end of the month they received one filling a day; and from 1st October and onwards they received two fillings a day, as described above.

On the 13th and 14th of October, 1902, Dr. Cayley made the following analyses: A sample of crude sewage entering the Liquefying Tank at 8 A.M., on 13th October was taken by removing a certain quantity of sewage every ten minutes until a bucket was filled: the sewage was then stirred and mixed, and a bottle removed for analysis. Dr. Cayley describes the sample as "thick, dirty yellow; considerable quantity of fæcal sediment; offensive smell."

	Crude Sewage.	Effluent from Liquefying Tank.	Effluent from No. 1 Contact Bed.	Effluent from No. 2 Contact Bed.	Proportion.
Free Ammonia ...	11·300	9·408	4·704	2·640	Parts per million
Alb. Ammonia ...	26·450	2·520	1·740	1·180	
Total Solids ...	102·00	23·00	16·00	15·00	Grains per gallon.
Suspended Solids.	53·00	3·00	...	...	
Chlorine	3·6	2·4	2·1	2·05	
Nitrites as NO_2...	...	...	...	0·115	Parts per 100,000.
Nitrates					
as N	...	...	...	0·5	
as NO_3 ...	...	...	...	2·214	

During the fortnight succeeding the 15th of October, 1902, a very striking improvement was noticed in the effluents from both the contact beds. This was undoubtedly due to the fact that the beds were getting into good working order and also to the increase in the temperature of the sewage. An estimate of oxygen absorbed in four hours, made by Dr. D. A. Turkhad, M.B., C.M. (Edin.), on the 18th October 1902, of the effluent of the 2nd Contact Bed gave a result of 1·35 of absorbed oxygen in parts per 100,000. A similar estimation made on the 25th October following, also by Dr. D. A. Turkhad, gave a result of 0·42, shewing a large increase of purification in the week's working. On the 26th of October, 1902, an estimate, made by Mr. G. Midgley Taylor, M.I.C.E., F.C.S., of the effluent of the same contact bed gave 0·28 of oxygen absorbed in four hours in parts per 100,000.

These figures shew that after only six weeks' working a result is obtained equal to any in Europe, even after passing through a series of three contacts.

About the middle of June, 1904, that is to say, nearly twenty-one months after the beds were started, an experiment was made by shortening the time of the contact to only one hour in each bed; but the result of the weekly analyses was unsatisfactory, and after working the beds for two months with the lessened contact. the original arrangement was restored.

The contact beds were started in October, 1902, and they have been worked daily for just under three years, during which time the silting up has been very gradual, indeed. At the end of August, 1905, it was found by careful observations that No. 1 bed had silted up to the extent of 25 per cent. of its water capacity, and No. 2 to a considerably less extent. For three years working this must be considered a satisfactory result. It remains to be seen how long the beds will take to right themselves, for from the 1st

September, 1905, neither of them has been in operation, but on refilling the beds on the 15th February, 1906, it was found that they had thoroughly cleared themselves and were again in perfect working condition.

The average of analyses for absorbed oxygen, taken weekly for about eighteen months, gives the effluent from the 1st Contact Bed as 0·46 per 100,000 parts, while for that from the 2nd Contact Bed as 0·29.

Of all the combinations above described, there is little doubt that a Liquefying Tank, combined with a continuous filter, gives the purest effluent and an effluent which is in many ways actually better than much of the water considered to be potable in India. But the process under this combination is a comparatively long one, even in the climate of India, as it takes between eight and nine hours to be complete.

The combination of the Macerating Tank and the 5-foot Ducat Filter has been very successful at Matunga, the process taking only some twenty-five minutes, that is, five minutes through the Macerating Tank and twenty minutes through the filter; but it has the drawback, and it is rather a serious one, of not giving a satisfactory effluent ordinarily until some months after it has started. It is doubtful whether a Ducat Filter by itself dealing with crude sewage should be recommended for use in a large way. It has been eminently successful at Matunga, dealing only with pure domestic sewage, but for use on a large scale some previous treatment of the sewage is desirable for the reasons previously given.

As pointed out, land in India is generally available for sewage farming, and nothing more than treatment of the sewage in a Liquefying Tank is therefore necessary. Such a purified sewage as is obtained from the combinations described, is not worth the expense necessary to obtain it, and the extra purification gives no special

advantage over the Liquefying Tank effluent when it is to be applied to the irrigation of crops. Effluent from the various combinations has been several times tried upon the crops at Matunga, but the result was not commensurate with the expense of building the filters.

Of all the "Distributors," probably some form of a circular sprinkler gives the best results. All tipping troughs have the fault of ridging fine filtering material. The orifices in fixed pipes are liable to choke, but this disadvantage is not so noticeable in rotating arms, the Adams' type of which has given satisfaction at Matunga.

The best filtering medium used at Matunga has been coal clinker. "Over-burnt brick," after being in use for some months, degrades badly, and so to a lesser extent does English coal; but if clinker is carefully picked, there will be no degradation for years. Probably the best material is coke, but its cost is somewhat prohibitive.

The Author has had the opportunity of reading the able and interesting paper by Major Ernest Roberts, I.M.S., published in "Scientific Memoirs by Medical Officers of the Army of India," Part XII, 1801; but the limits of this chapter only admit of a very brief reference to it.

The biological deductions recorded by Major Roberts are not altogether in agreement with those ascertained in Bombay. Major Roberts has laid considerable stress on the necessity of providing three distinct stages for the purification of sewage: First, anærobic through a Liquefying Tank, either closed or open, or by upward filtration on the Scott-Moncrieff plan ; secondly, intermittent downward filtration; and thirdly, filtration through porous arable land. He also states that it is undesirable to depend solely on downward filtration, and recommends a combined Scott-Moncrieff and Intermittent Downward Filter for Cantonments.

The experiments at Matunga have now lasted for over ten years, and though the sewage is in quantity only some 20,000 gallons per day, still the opportunities for observing biological results have been greater than elsewhere in India. Further, although the sewage flowing into the Liquefying Tank is only of average strength and dilute, that supplied to the Ducat Filter is stronger and equal to 10 gallons per head.

One of the very prominent results demonstrated at Matunga shews that an eight hours purification in a Liquefying Tank and a subsequent fifteen minutes passage through an Ærobic Filter (*i.e.*, two processes) is sufficient to give a very high purification result. Also that sewage passed through a Macerating Tank, which is an improvement on a Scott-Moncrieff Upward Filtration bed, does not give immediately satisfactory results, as has been shewn earlier in this chapter in regard to the 5-foot Ducat and the Stoddart Filters.

Major Roberts states that the "Dibdin, Ducat, and "Absaf processes are entirely unsuited to the concentrated "sewage of Cantonments and of Natives, even with the "most extravagant preliminary dilution with water."

The reverse has been the experience at Matunga, where an 8-foot Ducat Filter, dealing with crude sewage derived from a colony of sweepers, has been working continuously for five years. The amount of water (originally 40 gallons per head and now only 10 gallons per head) supplied with the sewage to the filter is measured by meter, so that the extent of dilution is not open to question, and the success of the filter has not been exceeded in any installation that the Author has seen. There has been no appreciable choking in the body of the filter, neither was there any trouble at the start, as in about six weeks it was in good working order.

As already stated, of all the combinations that have been discussed in the foregoing pages, the Author considers that a Liquefying Tank combined with a Continuous Ærobic Filter, will give the greatest satisfaction. A Liquefying Tank should be constructed to give a contact of eight hours in a climate where the temperature does not fall below 55° F. In districts where the temperature falls to freezing point and even below it, the tank should be constructed to hold from 12 to 24 hours' supply of sewage.

A satisfactory depth for an Ærobic Filter is 7 feet. If that depth can be attained, success is assured. The filtering material should be either coke or coal clinker, any other filtering material, though suitable in other respects. being apt to degrade in time. The size of filtering material should range between 3 inches as a maximum and 2 inches as a minimum.

The most economical construction of a filter is shewn in Plate 55. Wire is easily obtainable nearly everywhere and it is also cheap. Undoubtedly, the success of the recent Stoddart Filter at Matunga is largely due to its open sides, for although open sides are not a necessity in cases where air can freely penetrate the filter from the top, yet with closed distributors, such as Stoddart's, the Author is of opinion that open sides are desirable.

The day of contact beds has passed ; and although purification may be eventually satisfactory, the process is long and there is the certainty that they will eventually silt up to a greater or less extent.

In the appendix attached to this book, there will be found an interesting joint account by Messrs. Owen Travis, M.D., Bar.-at-Law, and Edwin Ault, C.E. The process which these two gentlemen put forward takes place in what they term "a Hydrolytic Tank" and "Oxydising Bed." Briefly, they advocate the abolition of Liquefying Tank treatment, excepting so far as sludge is concerned, and

would merely pass the sewage through a settling tank at a just sufficient velocity to deposit the organic matter: the sewage is then passed on to the Oxydising Beds, and it is claimed that the process not only takes a much shorter period but also gives a better purificatory result than the present method of Liquefying Tank treatment and continuous filtration. Sufficient experience has not yet been obtained to state whether this improved process will be entirely successful, but from the account published the process seems to promise well.

One of the worst forms of sewage that the Sanitary Engineer has to deal with, and one that is often met with in India, is undoubtedly that from tanneries. It is usually composed of spent lime and other chemicals, highly charged with organic matters, both of animal and vegetable origin. Sewage of such composition as this cannot be treated biologically; it can only be satisfactorily dealt with either by chemical treatment or by passing it through precipitating tanks, after first cleaning out floating matter such as hair, etc., and afterwards largely diluting it with fresh water and discharging it either into the sea or a river. The usual method of treating tannery sewage in England is to add Sulphate of Alumina, which can be cheaply purchased under the trade name of Alumino-ferric.

The chemical effect of the addition of alumino-ferric to tannery sewage, which is strongly alkaline owing to the lime used in the tanning process, is to produce a dense precipitate, which in settling carries down solid matters and also certain portions of dissolved organic matter, at the same time removing a large proportion of the colour from the effluent. The effluent, however, from the tank is, even after being chemically treated, of a foul and offensive nature. All tannery sewage, before entering the precipitating tank, should be efficiently screened through screens with spaces not more than ½ inch wide. The bars

of these screens should be rectangular in shape, the screens themselves sloping at an angle of 45°, a hand rail being provided at the top to enable the raking of the screens to be easily and safely effected. A scum board should also be placed across the tank to catch any floating substances that evade the screen. All screenings and surface floating matter removed from the tanks should be burnt. The solid matters retained in the precipitation tanks will require to be removed from time to time, and the best means of doing this is by employing a chain pump.

It is desirable in case of all tanneries that arrangements should be made to compel each owner to treat the sewage of his own tannery before it leaves the premises.

CHAPTER VI.

TANK GAS.

In dealing with the subject of gas obtained from a Liquefying Tank, the Author has decided to relinquish the use of the term "septic gas" hitherto employed and to substitute therefor the term "tank gas," as being a more practical term in relation to the particular gas in question, which consists of four constituents, namely, marsh-gas (CH_4), hydrogen (H), nitrogen (N), and carbon dioxide (CO_2); for while this combination has no specific name in Chemistry, the use of the word "septic" to represent it may be considered to be a misnomer, particularly because that word has a specific use in Surgery and refers to the putrefactive or animal poisons which permeate the blood and, having exclusively organic origin, is associated with Bacteriology. Under these circumstances, the change is rendered desirable and has the sanction of practicality at least to recommend it until a better term is found to supersede it.

In the opinion of the Author, there is a great future for tank gas in the East; for, in the first instance, beyond the first cost of covering a liquefying tank and the construction of a gas holder and a purifier, there is no further cost for generating the gas. Then again, after being purified, the tank gas can be used for power in a gas engine to actuate any machinery, and also for heating or lighting. *Quisque sua lampas!*

At Matunga, all the gas that can be obtained from the liquefying tank is made use of in one or other of the three

above-mentioned ways. The daily supply is fairly constant, while the quantity is only limited by the population. the average temperature, and the pressure at which the gas is drawn off. It must be remembered that the gas is highly explosive, and as this is the case, care is necessary in dealing with it, the insertion of a piece of gauze in the gas delivery pipe being desirable to prevent firing back.

EXPERIMENTS AT MATUNGA.

Since the early part of 1902, the Author has been experimenting with the gas generated in the liquefying tank at Matunga. Early in that year the No. 1 Compartment of the tank was covered with a galvanized iron gas-tight cover of a semi-circular shape, which was laid on the side walls on a jointing of red lead and bolted firmly to the masonry. This mode of fixing the cover did not prove altogether successful and many coatings of pitch were subsequently required to make it gas-tight.

At a later date, when covering the second compartment of the tank, the iron cover was so constructed as to rest on a ledge in the walls some nine inches below the surface of the sewage, which thus formed a water seal. This method proved to be quite satisfactory and allowed of the cover being placed in position without any trouble. At one end of each cover two inspection doors are fixed to give access to the tank when necessary.

In covering the liquefying tank, it must be remembered that no other material is so suitable as iron, as admixture with the outside atmosphere is fatal to the well-doing of the gas. With any material, such as brick-work or concrete, even when covered with a layer of earth, the gas will find its way through. Even with an iron cover, great care must be exercised in making the joints, which should invariably be made with tape.

In the earlier experiments that were made, which are described in the Author's *Oriental Drainage*, only a small gas-holder, 5 feet in diameter and 4 feet high, was used. At that time only one compartment of the liquefying tank was covered. When the second compartment was covered, two large gas-holders were erected: the larger of these is capable of holding 1,200 c.ft. of gas, and the other 600 c.ft., while the smallest holder holds 60 c.ft. only. All three holders are in communication with each other and can be filled one from the other at will. The gas is drawn off from the roof of the tank through a 4-inch cast iron pipe, by means of the suction action produced by the gradual raising of the gas-holder by counterbalance weights, and is first led into the purifier, a small drawing of which is given in a corner of Plate No. 54. In the purifier, the gas is passed through slaked lime to remove the carbonic acid gas. After passing through the purifier, it is conducted by a 4-inch pipe into the gas-holder. The section of the gas-holder shews two pipes fixed in the centre, one a 4-inch pipe for filling the holder and the other a 2½-inch pipe for the delivery of the gas, for whatever purpose it may be used. The diameters of the entry and exit gas pipes are governed by the size of the installation.

Much care is required in the construction of the gas-holder. After the gas-holders are once in position, leaky joints are very difficult to deal with. A gas-holder should be rivetted on the spot at which it is intended to be erected and all the joints should be most carefully made with tape. The same remark applies to the purifier. At the lowest points of the gas pipes a cock should be inserted for the removal of any condensed water. This is very necessary, for water accumulates in the pipes to such an extent as in time to completely stop the gas from passing through. Another necessary precaution is the placing of a piece

of copper gauze on the entry and exit pipes to prevent any chance of the gas firing back.

Plate No. 54, which is a plan of the Biological Installation at Matunga, shews also the details of the gas arrangements now in use.

A similar experiment with gas is said to have been made at the Exeter Sewage Disposal Works at Belle Isle by Mr. Donald Cameron, M.I.C.E., the late City Engineer, and there the gas was drawn from the cover of the tank. by an aspirator or fan, to supply the power for working a gas engine and for illuminating purposes. It is said that at Exeter, roughly, one cubic foot of gas was obtained per head of population per day at an average temperature of about 55° F.

Dr. S. Rideal, who analysed the gas at Exeter on two occasions, gives its composition in percentages by volume as follows:—

Carbonic Acid	0·3	0·6
Marsh Gas	20·3	24·4
Hydrogen	18·2	36·4
Nitrogen	61·2	38·6
Total	100·00	100·00

Broadly speaking, it may be said that tank gas is made up on an average of 20 to 24 per cent. of marsh gas and 18 to 36 per cent. of hydrogen, or, say, altogether an average of 50 per cent. of combustible gases; so that the quantity of gas necessary for each brake horse-power for working a gas engine would be double that of ordinary coal gas.

An analysis made by Major Collis Barry, I.M.S., Chemical Analyser to Government, of the gases collected from the tank at Matunga is as follows:—

Carbonic Acid	5·32
Marsh	21·25
Hydrogen	13·52
Nitrogen	60·00

It will be noticed that the composition of the Matunga gas closely corresponds to the analyses made by Dr. Rideal of the gas from the Exeter Works. An important difference is, however, apparent in the percentage of the Carbonic Acid Gas, which is much larger at Matunga than at Exeter. This is no doubt due to the difference in the temperature of the sewage and probably the pressure at which the gas is drawn off. Carbonic acid gas is very soluble in sewage, the amount which the sewage can contain being dependent upon the temperature of the sewage and upon the pressure of the gas over the surface of the sewage.

The above results are borne out by several analyses of the gas made by Captain Glen Liston, I.M.S., the percentages of one of which are as follow:—

CO_2	16·0
CH_4	23·9
H	11·99
N	48·00

Captain Glen Liston makes the following interesting remarks on the gas after several analyses:—

"CO_2 variable from 5%, when engine was going fairly "well, to 11% when just going and to 16% when not going "at all. No oxygen, or an almost inappreciable quantity, "was ever found in the gas. No CO (Carbon Monoxide) "was ever found. The amount of Hydrogen varied from "12 to 20 per cent. The amount of CH_4 varied from 24 "to 32 per cent. The amount of N varied from 48 to 60 "per cent."

It was found that when the percentage of CO_2 present in the gas was high, the engine would not go, and that the engine went best when the CO_2 was low, hence the necessity for getting rid of the CO_2. The method at first adopted was defective, because the lime was not slaked properly. The presence of carbon dioxide is very harmful.

both in the working of the engine, lighting, or the burning of the gas. It must be got rid of. The constituents of the gas which are useful for combustion or lighting are hydrogen and marsh gas. The amount of these two gases present was variable. The best results are obtained when the highest percentage of hydrogen is present. Hydrogen, when it is burnt, produces only water vapour, while marsh gas produces carbon dioxide and water vapour. The former constituent has a damping effect on further combustion.

The larger part of the gas consists of nitrogen. This is a diluting constituent. It was present in variable quantities, no doubt depending on the various factors mentioned above. The gas is often so diluted with nitrogen that it will not explode when mixed with ordinary air under atmospheric pressure. When this is the case, an increase in the pressure at which the gases are exploded will cause combustion. This is important when a gas engine has to be worked. The gas must be well compressed before explosion. In analysing the gas, oxygen has often to be added to effect an explosion. The quantity of nitrogen present in the gas probably depends on the pressure at which the gas is drawn off. The lower the pressure in the tank chamber below atmospheric pressure, the greater will be the quantity of nitrogen in the tank gas.

The tank gas at Matunga is utilized in three ways—(*a*) to actuate a gas-engine, (*b*) to light the compound and buildings, and (*c*) for cooking.

In 1902, an Otto Gas engine, of ½ H.P. Nominal, capable of developing 3 Indicated H.P. with a consumption of 22 c.ft. of coal gas per H.P. per hour, was erected. This engine works a 3-inch centrifugal pump of the ordinary type, fixed in a brick chamber six feet in depth. The pump lifts the effluents from the liquefying tank to a tank fixed some ten feet above the ground. From this tank the

effluent flows by gravitation to the contact beds and filters described in the previous Chapter.

Further experiments are necessary to determine the best type of engine to work with tank gas, and it is probable that an engine built to work with Mond, a "Producer Gas," would be the most suitable. At Matunga the gas engine for many months in the beginning gave uncertain results, and had to be considerably altered before it could be got to work satisfactorily. A regulating valve had to be placed on the air admission pipe to reduce the quantity of air in the mixture, and at the same time more gas had to be admitted than would be the case with coal gas. The engine still suffers from contracted gas passages, and the result is that it will not give off the rated horse-power on the brake. A shorter ignition tube had to be put in to secure an earlier ignition, as it was found that frequent misfires occurred with the standard tubes originally attached to the engine.

The engine still occasionally misses one stroke in four, otherwise it gives great satisfaction and works without difficulty. It is possible that some of these difficulties would be overcome and a considerable saving in gas effected by using magnetic ignition, with an arrangement for advancing or retarding the spark.

The up-keep of the engine is exceedingly light, lubrication being the principal item of cost. Approximately this size of engine will use about 130 c.ft. of gas per hour of work. The experience at Matunga has been that to get the best results from the engine, the CO_2 must be almost entirely eliminated.

Practically, the whole of the lighting of the Acworth Leper Asylum at Matunga is now done with the tank gas derived from the liquefying tanks. Pipes varying in size from 2½ to ½ inch at the lamp posts have been laid from the gas-holders all over the Asylum grounds.

The burner for tank gas is a modification of the one usually used for ordinary coal gas with an incandescent mantle. The alteration chiefly affected the size of the opening which admits air to mix with the coal gas. As tank gas requires considerably less oxygen for its complete combustion than coal gas, the air opening in the burner had to be much smaller. A collar to regulate the size of the opening gives the most satisfactory results.

When the pressure is greater, more gas will be used and the mantle will become hotter, giving out more light; in other words, it will give a higher candle-power. When the pressure is low, less gas will be burnt, less heat evolved, the mantle will be less brilliant, and the candle-power will be less. Any kind of incandescent mantle which is satisfactory with coal gas can be used with this gas. The amount which each gas lamp will burn varies according to the candle-power desired.

The kitchens at Matunga are now fitted with gas rings and much of the cooking is done with tank gas. There are eight stoves so fitted and the food for the patients is cooked daily at these. The consumption of gas is heavy, but as its production costs nothing, that is of little moment. About 300 cubic feet of gas are used both morning and evening and the saving in wood fuel to the Asylum is large.

At another installation which is under construction in connection with the sewerage of Bombay, it is proposed to utilize the gas for burning the screenings in a small district.

Having dealt with the experiments at Matunga with tank gas, it will be well to consider the conditions which influence the quantity and quality of the gas.

At Matunga, the population is 430 persons. For the last twelve months, careful observations have been taken of the amount of gas obtained, the temperature of the air,

and the temperature of the sewage. The amount of sewage passing through the liquefying tank is at present equal to 30 gallons per head per day. The conditions affecting the quantity and quality of the gas may be summarized under the following four heads:—

I.—Quality of sewage.

II.—Pressure at which gas is drawn off.

III.—Bearing which temperature has on evolution of gas.

IV.—Velocity of sewage and disturbance of sediment.

I.—**Quality of Sewage.**—The amount of gas produced will depend greatly on the quantity of nitrogenous and non-nitrogenous elements present in the sewage and undergoing disintegration.

Major Ernest Roberts, I.M.S., in his paper published in "Scientific Memoirs by Medical Officers of the Army of India," Part XII, 1901, states that with the natives of India the unabsorbed proteid from vegetable foods amounts in the excrement from 10 to 20% of the total ingested, and that from 30 to 50% of the cellulose leaves the body in its integrity.

Professor Sims Woodhead, M.D., stated in his evidence before the Royal Commission on Sewage Disposal that, in the ordinary domestic sewage, the nitrogenous constituent of the sewage is always relatively small, the greater bulk being non-nitrogenous cellulose or the like, and that the cellulose is converted into carbonic acid and marsh gas. It would appear from this, with other things being equal, that the gas obtained from the sewage in the East should be equal in amount to that obtained from the sewage in the West.

Professor Sims Woodhead is probably correct when he says that the non-nitrogenous elements in the sewage, es-

pecially vegetable matter, are best for the formation of tank gas. As the large mass of the natives of India are vegetarians, the sewage of the East is likely to be a better producer of gas than that of the West.

Any addition of what is known as "trade refuse" will usually rather retard the formation of gas than otherwise. At the present time, practically nothing is known as to what bacteria are necessary for the production of gas, affecting at the same time a satisfactory purification of sewage. But it is an established fact that it is possible to cultivate suitable bacteria in a liquefying tank by depositing in it some of the sediment taken from a tank which is in full working order. This has been done often in Bombay and many new tanks have been successfully supplied with the required bacteria cultivated from the sediment of the Matunga Liquefying Tank.

The dilution of the sewage has a very important bearing on the quantity and quality of the gas formed. As an instance of this, the Author can cite an interesting experience obtained at the Empress Mill in Bombay. Here a large installation of latrines used by some 6,000 mill hands has been connected to a covered liquefying tank, to which is attached a gas installation similar to that at Matunga. The gas obtained is used for a gas engine and for lighting the Mill compound.

From the first, the liquefying tank was cultivated with bacteria from Matunga, and in a short time gas commenced to be evolved. The amount of water used at these latrines was in the beginning equal to only one gallon per head per day. This quantity in the course of three months proved to be inadequate for complete purification in the tank, and although large quantities of good gas were given off, the tank became almost choked, while the effluent was only partially purified and had a very offensive smell.

The amount of water was increased to three gallons per head and the immediate result was a better effluent and also an increase in the evolution of gas, which was of excellent quality for purposes of combustion. A further increase of water to five gallons per head resulted in a further improvement. At five gallons per head, the quality of the gas was still excellent, and after purification gave very good results in the engine and for lighting.

The above is interesting as shewing that even with exceedingly strong sewage and very little dilution, good gas can be obtained, though not in such quantities as is possible with sewage diluted under ordinary circumstances.

II.—**Pressure at which Gas is drawn off.**— The pressure at which tank gas is drawn off has an important influence not only on the quantity of the gas but also on its quality, as well as on the purification of the sewage.

The Author has found that if, in a covered liquefying tank, there are no arrangements to allow the gas to pass or to be drawn off as it is formed, the carbonic acid gas is absorbed by the sewage and purification is not so rapid or complete.

An ordinary glass gauge half filled with water has been fixed on the cover of No. 1 Compartment of the liquefying tank at Matunga, for the determination of the pressure of the gas in the cover and of the vacuum necessary for drawing it off into the gas-holder. Observations have shewn that although the gas has been allowed to remain in the cover without being drawn off for a day or two, no pressure has ever been indicated in the gauge. On the other hand, as before mentioned, this has been extremely detrimental to the purification of the sewage. It has also been noticed that if gas is allowed to remain in the cover, it gives off some of its carbonic acid gas, which is absorbed by the sewage. When the largest gas-holder is drawing gas at Matunga, the gauge shews the vacuum to be equal to

about half an inch of water. Further careful experiments are necessary to determine the pressure at which the greatest amount of gas can be obtained, consistent with good quality.

It is always necessary to employ some power to remove the gas from the cover of the tank. This may be done either by suction as before mentioned or by means of a fan or vacuum pump. It has been found that if gas is drawn off too rapidly or in too great a quantity, the quality of the gas for purposes of combustion is very inferior, and great difficulty is experienced in using it successfully.

III.—**Bearing which Temperature has on Evolution of Gas.**—Charts have been prepared from time to time shewing (*a*) the temperature of air, (*b*) the temperature of the sewage, and (*c*) the quantity of gas removed from the tank at Matunga. It must be remembered, while considering the amounts of gas recorded below, that only two compartments of the tank out of four have been covered, and it is probable that these amounts would be increased by at least 20 % if the whole of the tank were covered and the full quantity of gas that could be given off by the sewage collected:—

The charts shew that temperature has a large bearing on the amount of gas produced. The lowest mean temperature of the sewage registered in 1906 was on the 12th January, 1906. It was then 71·5° Fahrenheit. The lowest mean temperature of the air on that day was 67·8° Fahrenheit, and the amount of gas obtained from the two compartments for 24 hours on that day was 1,050 c. ft. On the 30th of the same month the mean temperature of the sewage was 73° and that of the air 78·8.° The amount of gas obtained on that day was 1,350 c.ft. On the 15th February, 1906, the mean temperature of the sewage was 75° and that of the air 80°, and the amount of gas obtained was 1,550 c.ft. The above shews that, with a rising tempera-

ture, the volume of gas is proportionately increased. It may be mentioned that in all cases the pressure at which the gas was drawn off was uniform. In May—the hottest month of the year in Bombay—the mean temperature of the sewage is about 89°. As all the three gas-holders were not in work in May, 1905, it is not possible to say exactly what amount of gas would be evolved at the temperature of 89°, but it would probably be far in excess of that obtained with the above temperatures. In the opinion of the Author, it would be quite safe to calculate upon an average volume of 3 to 4 c.ft. of gas per head of population per day throughout the whole of the twelve months.

IV.—**Velocity of Sewage and Disturbance of Sediment.**—The velocity at which the sewage passes through the liquefying tank has also an important bearing on the quantity and quality of the gas; for it stands to reason that when the sewage passes rapidly through the tank, purification is incomplete and the quantity of gas evolved is therefore less. In the opinion of the Author, the maximum velocity of the sewage in order to attain the best results as regards both the purification of sewage and the evolution of gas, should not exceed one foot in three seconds.

An interesting experiment was tried in both the covered compartments at Matunga with an "agitator" for stirring the surface of the sediment. The agitator consisted of a flat bar of iron attached to chains, one end of which passed out through the end walls of the tank. It was found by dragging the agitator over the surface of the sediment that a much larger quantity of gas was evolved than under ordinary circumstances; but it was of such impure quality that it could not be used for working the engine and was also of very little use for lighting. It evidently contained not only a large excess of CO_2, but it was also deficient in marsh gas and hydrogen.

A few concluding remarks will not be out of place here as to the general use of tank gas. In the first place, there need be no anxiety or doubt as to the possibility of obtaining

gas from a scientifically designed liquefying tank as at Matunga, where the use of tank gas has now been brought to such a state of perfection that from day to day the gas is removed from the liquefying tank, purified, passed into a gas-holder, and used for the purposes enumerated earlier in this Chapter with as great a certainty as the drawing of water from a tap.

The thanks of the Author are due to Captain Glen Liston, I.M.S., for a valuable description of the "Method of Analysing Tank Gas," which forms an Addendum to this Chapter and will be read with interest. It would be out of place here to enter into any detailed discussion as to the methods employed in gas analysis, but a few remarks on a fairly accurate and practical method for analysing tank gas will probably serve a useful purpose. Very little is yet known of the conditions which influence the production of gas in sewage, and still less is known of the qualities and composition of the gas evolved in the complicated putrefactive changes which take place in a liquefying tank; and therefore any progress in this direction can only be attained after a large number of analytical observations have been made under varying conditions.

A simple and practical method, capable of being carried out with a fair degree of accuracy by a Medical Practitioner or a Sanitary Engineer, will help greatly in the solution of this difficult problem.

A proper use of the apparently waste gas from sewage, as will be seen in the earlier part of this Chapter, leads not only to the saving of a considerable sum of money in lighting and heating, but enables an Engineer to get over such practical difficulties in the disposal of sewage as those connected with finding a suitable fall. The possible use of the properly purified gas in the destruction of solid waste material, rubbish of all kinds, and sweepings must be kept in mind.

ADDENDUM.

METHOD OF ANALYSING TANK GAS.

By Captain Glen Liston, I.M.S.

The description of a method for making an analysis of tank gases can most conveniently be divided into the following heads:—

I.—Collection of gases.

II.—Measurement of gases.

III.—Estimation of Carbon Dioxide.

IV.—Estimation of Hydrogen, Methane, and Nitrogen.

I—Collection of Gases.—This is most conveniently done in specially made gas sampling tubes or flasks. These are cylindrical glass vessels drawn to a point at both ends and fitted at each end with a glass stop cock. Where the supply of gas is abundant and is given off under a certain pressure, the sampling gas flask is easily filled by attaching one end of the flask by means of a rubber tube to a suitable tap or stop cock on the gas supply pipe. The flask having been adjusted by means of the rubber tubing, all the cocks are opened and the gas is allowed to pass rapidly through the flask for a few minutes till all the air has been completely expelled. The taps are then closed and the flask detached from the gas supply pipe. Where the gas is not given off under pressure, another method has to be adopted. Such a condition exists when a sample of gas has to be taken from the tank before it enters a gas-holder. For this purpose the gas sampling flask should be completely filled with water. A tap should

be fixed to the bottom of the outlet pipe from the liquefying tank as shewn in Fig. 35. The rubber tube attached to the

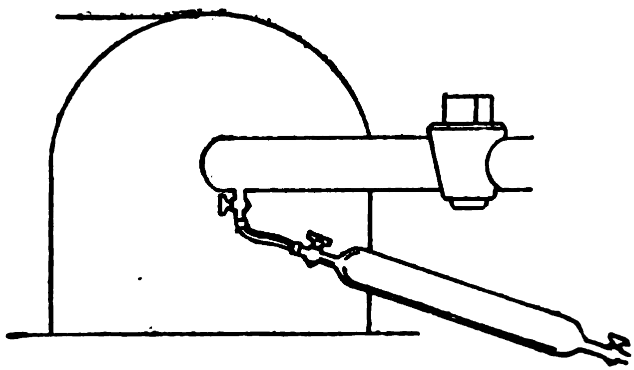


FIG. 35.

sampling flask, which is filled with water should now be adjusted to the tap on the outlet pipe. The tap on the outlet pipe is then opened. The cock on the distal end of the sampling flask should next be opened, the water will then flow out of the sampling flask and be replaced by gas from the liquefying tank. Having thus collected the gases, they have next to be measured.

II.—MEASUREMENT OF GASES.—The apparatus in which the measurements are made is called a gas-burette and consists of a graduated tube A and a pressure tube B. The tube has at the top an ordinary glass stop cock and near the bottom a three-way tap, which allows of communication being established with the pressure tube or with the air, according to the position in which the tap is turned. The space between the two taps has a capacity of 100 cc. and is graduated into cubic centimetres and fractions thereof. The graduations are numbered so as to be read either up or down the burette by means of a double row of figures. The whole burette is mounted on a suitable firm stand. The base of the burette is connected by means of a rubber tube with the base of the pressure tube. The length of the rubber tube should be such that the base of the pressure tube can be raised to

the top of the burette without dragging on the tube. It is convenient to have a piece of glass tubing inserted at the mid point of the rubber tubing to act as a window and to serve as a means for readily detaching the pressure tube from the burette without removing the rubber tubing from either the pressure tube or burette. The gas in the measuring tube is confined over water, and since most gases are readily soluble in water, the water used in the pressure tube should have been previously saturated with the gases to be tested. This is readily done, either by passing some of the gases through some water contained in a bottle, *e.g.*, when the gases are given off from the gasometer, or when this cannot be done, when testing the gases directly from the tank, the following procedure should be adopted. A stoppered bottle of about 300 cc. capacity is filled with water and inserted in a water trough; about 100 cc. of the gaseous mixture to be tested is bubbled up into the bottle, which is then closed with the stopper and the gas thoroughly shaken up with the remaining water for a few minutes.

To pass the gases into the burette is the next procedure. To do this a piece of capillary glass tube is bent twice at right angles as in Fig. 36 (overleaf), and is attached to the burette as shewn by means of a rubber tubing, which should be wired to the glass at both joints. The pressure tube, which has previously been filled with water saturated with the gas to be tested, is now raised and the water allowed to fill the burette and drop from the end of the bent capillary tube. The gas sampling flask is next taken in hand, and both open ends are filled with water ; one end is inserted into a rubber tube at the end of the bent capillary tube and the other end is placed in a conveniently situated flask of water. The stop cocks of the sampling flask are now opened: both cocks on the burette are also opened: the pressure tube is gently lowered. The gas to be tested will now pass into the burette and be replaced by water in the sampling flask.

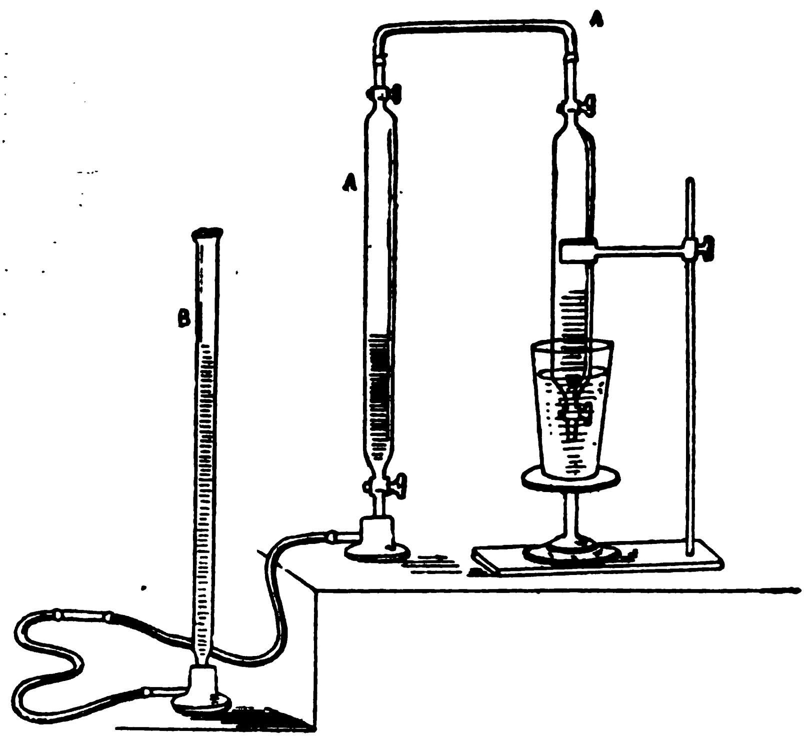


FIG. 36.

When the gas has completely filled the burette to a point a little below the bottom of the stop cock, the cocks of the sampling flask and the stop cock of the burette are closed. The pressure tube can now be placed on the table beside the burette while the collecting flask is detached. Next, after the collecting flask has been removed, the pressure tube is again lowered till the level of the water in it is the same as that in the burette. The cock at the top of the burette is now opened gently and the pressure tube raised very gently till the water in it is exactly level with the 100 cc. mark at the bottom of the burette: the stop-cock at the top of the burette is now closed, and the burette is filled with 100 cc. of the gas to be tested.

III.—ESTIMATION OF CARBON DIOXIDE.—This is accomplished in a special gas pipette illustrated in Fig. 37.

It consists of two bulbs connected together by bent glass tubing, the smaller or upper bulb (*a*) opens above by a rather large bore glass tube, through which tube the reagent for absorbing the gas is passed into the bulbs. Below, the smaller bulb is connected to the larger bulb by a V-shaped piece of tubing. The capacity of the larger bulb should be at least 150 cc. It is open above through a doubly bent capillary tube. Behind this capillary tube a piece of white paper is placed and a mark made upon the paper about the position represented in the diagram. The pipette has now to be filled with the absorbing reagent, which, for estimation of carbon dioxide, is a solution of caustic potash. The reagent is made by dissolving 150 grms. of commercial caustic potash in 500 cc. of water. The reagent is poured into the bulb through the wide tube at the upper end of the smaller bulb. Such a volume of the solution is filled into the pipette that, when it is sucked up into the capillary tube nearly to the top, there shall be just a small quantity of liquid in the smaller bulb.

The burette is now attached to the absorption pipette as in Fig. 37, care having been taken to draw the caustic potash solution up to the mark on the capillary tube of the bulb. The solution can be kept in this position by suitably adjusting the pinch cock on the rubber tube connecting the pipette with the

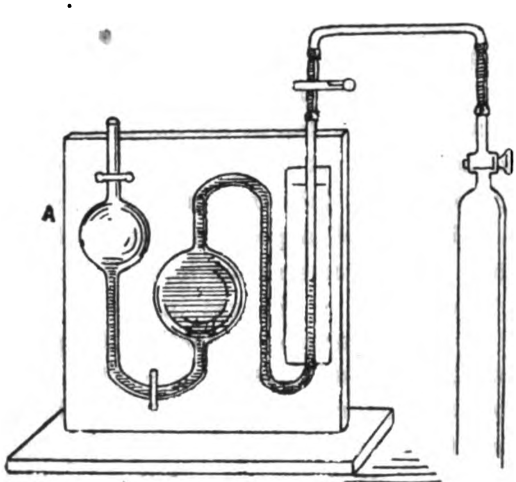


FIG. 37.

burette. After the connections have been made and securely fastened—by wire, if necessary—the pinch cock is opened by passing it on to the glass tube: the stop cock at the top of the burette is next opened and the pressure tube raised. In handling any of the apparatus care has to be taken to grasp the various parts only by the wooden fittings, which is necessary in order to maintain a uniform temperature throughout the different parts of the apparatus during the testing. The gas in the burette will be driven into the pipette and the burette will become filled with water. This process of transferring the gas to the pipette is to continue till all gas has been driven from the burette and until some of the water—a drop or two—from the pressure tube has passed into the larger bulb of the pipette. The tap at the top of the burette is then closed. The pipette is then gently shaken and the gas allowed to remain in contact with the caustic potash for a few minutes (three to five). After this time the pressure tube is lowered and the tap at the top of the burette again opened. The gas will then pass back again into the burette and the caustic potash solution will again fill the large bulb of the pipette. When this bulb is nearly full, the gas must be allowed to pass very slowly into the burette by adjusting the level of the pressure tube. As soon as the potash solution reaches the mark on the capillary tube, the tap at the top of the burette is closed. On no account must the potash be allowed to reach the rubber connection into the burette. The pressure tube is then held in such a position that the level of the water in it shall be the same as the level of the water in the burette. The volume of the gas in the burette is then read off and the same operation of passing the gas into the pipette—allowing a few minutes for absorption of the carbon dioxide gas and returning the gas to the burette, adjusting the level of the water in the burette and pressure tube, and again reading off the volume of the gas in the burette—is repeated. If both readings are the same, the

operation is complete and the amount of carbon dioxide present in the original gas can be ascertained thus:—Original volume of the gas 100 cc.; volume after absorption by Potash, 84 cc.; Carbon Dioxide, 16 cc. = 16% Carbon Dioxide.

IV.—ESTIMATION OF HYDROGEN, METHANE, AND NITROGEN.—This is carried out in a specially constructed explosion pipette, which differs from the ordinary absorption pipette only in having two platinum wires fixed into the upper part of the largest bulb and in being furnished with a stop cock on the U-shaped tube joining the two bulbs. The bulbs are filled with mercury in place of caustic potash solution, and the burette containing the gas after absorption of carbon dioxide is detached from the caustic potash pipette. Some oxygen is prepared by heating some chlorate of potash with some manganese dioxide in a suitable flask to which has been attached a gas collecting tube. The oxygen is allowed to pass through the tube till such time as the glowing spark of a wooden match is kindled into flame when held in front of the point of exit of the gas. The gas so prepared can be kept in stock and must be allowed to cool before being used. The collecting flask is now attached to the burette and some of the oxygen passed into the burette as described under the heading "Measurement of Gases." Sufficient oxygen should be added to completely combine with the hydrogen and marsh gas present in the mixed gases. The sampling flask containing the oxygen is then detached and the burette is adjusted to the explosion pipette. The mercury in the explosion pipette is first driven into the large bulb by adjusting a piece of rubber tubing to the glass tube opening into the smaller bulb, opening the stop cock between the two bulbs, and blowing the mercury into the larger bulb till it is filled and the mercury stands at a suitable mark on the capillary tube of the larger bulb. When this point

has been reached the tap between the two bulbs is closed and the burette is then attached as usual to the explosion pipette. Special care has now to be taken to use stout tubing to connect the pipette with the burette and all rubber connections must be firmly wired. When this is done the stop cock between the two bulbs is opened as well as the stop cock at the top of the burette. The pressure tube is raised and suction is applied to the pipe connected with the smaller bulb till all the gas has passed over into the larger bulb and with it one or two drops of water from the pressure tube. The tap between the two bulbs is then closed. The wires from a Rumkorf coil are adjusted to the platinum terminals in the larger bulb and a spark allowed to pass. The gas is now retransferred to the burette by opening the tap between the two bulbs and lowering the pressure tube till the mercury again stands at the mark on the capillary tube. The cock at the top of the burette is then closed and the burette is detached from the pipette. When the gas has been allowed sufficient time to cool, the level of the water in the pressure tube is adjusted to the level of the water in the burette and the volume of the gas now measured and noted. The burette is next attached to the caustic potash pipette and the amount of carbon dioxide absorbed is noted as described under the heading " Estimation of Carbon Dioxide." From these data the amount of methane, hydrogen, and nitrogen can be ascertained.

From the equation $CH_4 + 2O_2 = CO_2 + 2H_2O$, it follows that when marsh gas is burnt its own volume of CO_2 is produced; again, since H_2O practically ceases to occupy space, because the volume of condensed water is inappreciable, three volumes of the mixed gases CH_4 and O_2

shrink to one volume, *i.e.*, one volume of CO_2; the contraction, therefore, is two-thirds of the total volume of the reacting gases, or in other words equal to twice the volume of CO_2 produced, or twice the volume of marsh gas burnt; and again, from the equation $2H_2 + O_2 = 2H_2O$, and for the reason that H_2O ceases to occupy space, the volume of H burnt can be ascertained by measuring the contraction produced and multiplying this by $\frac{2}{3}$. If, therefore, the volume of CO_2 produced after explosion is measured and twice this volume be deducted from the contraction on explosion, the remainder will represent the contraction due to the combustion of hydrogen. Then if A = contraction on explosion and B = volume of CO_2 produced, A—2B = contraction due to hydrogen, and $\frac{2}{3}$ (A—2B) = volume of hydrogen and B = volume of marsh gas.

To continue the analysis of the sample of gas already tested for CO_2, as described under heading "Estimation of Carbon Dioxide," the burette, having been detached from the caustic potash pipette, now contains 84 cc. of the mixed gases, *viz.*, hydrogen, marsh gas, and nitrogen. A portion of this gas is driven out of the pipette so as to allow sufficient oxygen to be added to completely combine with all the hydrogen and marsh gas present in the mixture. Oxygen is added in preference to air, because the amount of nitrogen in the mixed gases is so great that a further dilution of the gas with more nitrogen from the air often prevents explosion.

Suppose then that 50 cc. of the mixed gases remained in the burette and that 50 cc. of oxygen had been added to this mixture as detailed above, and that the burette has been attached and finally secured to the explosion pipette, and that a spark has been passed and the explosion com-

pleted, and that the gases have been returned to the burette and allowed to cool, and the volume after explosion has been measured and found to be 60·73 cc., then the burette is detached from the explosion pipette and attached to the caustic potash pipette. The amount of CO_2 present in this residual gas is measured as described under heading "Estimation of Carbon Dioxide" and found to be 46·45.

From these data it is possible to give the composition of the gas as follows:—

The original volume of gas taken = 100 cc. After absorption in caustic potash pipette, Vol. = 84 cc., the remainder 16 cc. = CO_2 present in 100 cc. Then of the remaining 84 cc., 50 cc. are retained in the pipette and 50 cc. of Oxygen are added.

After explosion, Vol. = 60·73
∴ contraction, A = 39·27
After absorption in K O H, Vol. = 46·45
∴ B, Vol. of CO_2 produced = 14·28
Hence Vol. of Hydrogen in 50 cc. gas = $\frac{2}{3}$ (A − 2B)
$= \frac{2}{3}(39{\cdot}27 - 28{\cdot}56)$
$= 7{\cdot}14$
And Vol. of CH_4 in 50 cc. gas = 14·28
And Vol. of N in 50 cc. = 50 − (7·14 + 14·28) = 28·58

Calculating the percentages of these gases since the original volume of the gas was 100, and 84 after absorption of CO_2 and 50 cc. Volume of the residual gas tested, then—

$$\frac{7{\cdot}14 \times 84}{50} = 11{\cdot}99\% \text{ of H}$$

$$\frac{14{\cdot}28 \times 84}{50} = 23{\cdot}9\ \% \text{ of } CH_4$$

$$\frac{28{\cdot}58 \times 84}{50} = 48\% \text{ of N.}$$

A very excellent and accurate portable gas analysis apparatus has been recently described by Dr. J. S. Haldane in the *Journal of Hygiene*, Vol. VI, No. 1, and is shewn in Fig. 38. The method of working this apparatus has been

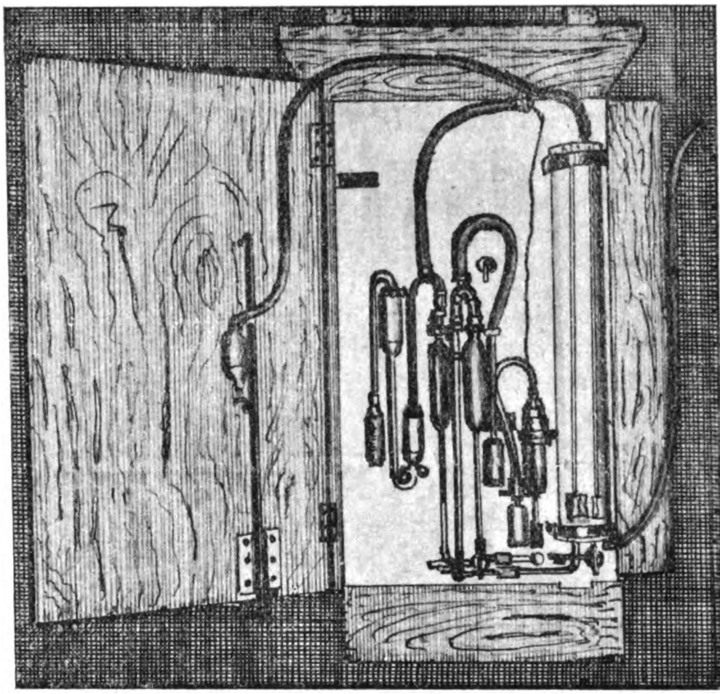


FIG. 38.

described by him in the *Investigation of Mine Air*, edited by Le Neve Foster and Haldane, 1904. The apparatus can be obtained from Messrs. F. P. Rettershaus & Co., 53 A., Huntly Street, Tottenham Court Road, London, W.C.

CHAPTER VII.

SURFACE WATER AND SUB-SOIL DRAINAGE.

Assuming that a separate system of drainage has been decided on, the question of disposing of the surface and sub-soil water of each district then calls for consideration.

The amount of rain which falls in a district is, in most centres, officially observed and recorded, and there are few places now where that information cannot readily be obtained for a series of years sufficient to enable a just average to be determined.

In a Separate System of Drainage, the capacity of the sewers must provide for that amount of rain which falls on such roofs and on such open paved surfaces enclosed by houses as cannot drain to the surface-water drain in the street without a special connection. The reason for this is that it is very undesirable to have both a sewage and a surface-water drain within house premises, as there would then be the risk of unsanctioned sullage connections being made to the surface-water drains, which would generally be more convenient from the householder's point of view.

Wide fluctuations of rainfall occur at different places, even in one district, and, as a rule, the rainfall increases with the elevation. A Meteorological Observatory, such as exists in Bombay, is of the greatest assistance to the Engineer, as valuable data extending over many years can generally be obtained therefrom.

In designing a scheme of surface-water drainage, the rainfall, the configuration of the land, and the area paved and built upon are the chief considerations.

In the case of towns on the sea-coast, the waters from high-lands should be separated from those of the low-lands: "high-lands" include lands at or above the level of the high-water mark of ordinary spring tides, and "low-lands" those below that level.

The waters from high-lands should be taken by drains discharging directly into the sea by the nearest route, the outlets being protected by means of tidal flaps. Those from low-lands will have to be stored during the time of high water and discharged into the sea through sluices at the ebb tide.

In the case of high-level drains discharging continuously and directly into the sea or a river without provision for storage, the maximum hourly rainfall is the chief factor in determining the size of such drains. Tables should be prepared from meteorological data to ascertain how many times a year the hourly rainfall exceeds certain quantities, and from such tables the maximum hourly rainfall to be provided for can be easily ascertained.

As an example, the following table shewing the number of times the hourly rainfall exceeded the given

Year.	Under ¼" per hour.	¼" to ½" per hour.	Above ½" to ¾" per hour.	Above ¾" to 1" per hour.	Above 1" to 1½" per hour.	Above 1½" to 2" per hour.	Above 2" to 2½" per hour.	Above 2½" to 3" per hour.
1886	497	31	17	8	5	4	2	1
1887 . . .	654	46	14	4	2	7	1	0
1888	479	39	9	4	0	1	0	1
1889 . . .	[illegible]	[illegible]	12	4	1	0	0	0
1890	620	46	10	0	3	0	0	0
1891 . . .	469	49	8	7	6	2	0	0
1892	622	71	20	11	4	1	0	0
1893 . . .	476	45	7	4	1	0	0	0
1894	597	46	6	0	2	0	0	0
1895 . . .	534	56	7	4	9	0	0	0
Averages ...	551·0	46·7	11·0	4·6	3·3	1·5	0·3	0·2

amounts in ten years (1886—1895) in Bombay will be found interesting. It will be seen that there were on an average only 5·3 hours in a year when the hourly rainfall exceeded 1 inch. Therefore, in Bombay, all high-level drains may be designed to carry 1 inch of rainfall per hour.

In the case of low-lands, the method for determining the size of the drain, etc., is different. It should be ascertained how many hours per tide, on an average, storage will be required, and the amount of the maximum rainfall for that number of hours consecutively should be obtained from the meteorological data, and storage, drains, etc., calculated for and provided accordingly.

Consideration must also be given to the amount of the rainfall that will flow off the surface of the ground. In fully built-upon areas, such as will be found in the centres of towns, it will be necessary to allow for all the rainfall to flow off, for the percentage that will soak into the ground is not an appreciable amount and need not be considered.

In suburban districts with gardens, etc., 65 to 75 per cent. of the rainfall must be provided for in a surface-water scheme, but in rural and sparsely populated districts only 10 to 20 per cent. need be taken into consideration. No definite rule can be laid down for the amount that will flow off in rural districts, the nature of the soil naturally having much to do with that amount.

One inch of rainfall in depth over one acre per hour is equal to 3,630 cubic feet, or 22,687 gallons, per hour, or just one cubic foot per second. Consequently, drains designed for an hourly rainfall of one inch should be capable of discharging as many cubic feet per second as there are acres to drain.

In India, where the rainfall is usually confined to a specific season of the year, heavy daily falls are not uncommon, but they are usually not of long duration, and

such flooding, as will temporarily occur, soon disappears and is more or less immaterial. In districts where the rainfall is small, the storm-water is generally loaded with impurities, particularly at the time of the first flood, analyses showing the liquid to be almost as impure as sewage; subsequent flows may, however, be comparatively pure.

The considerations which govern the directions of sewers in a sewerage scheme, will be even more applicable to the drains in a surface-water scheme, that is to say, they should always, if possible, follow the natural drainage of the district, and in this way nature provides the outfalls at which the surface water will discharge. The number of outfalls is not restricted as in a sewerage scheme and this tends considerably to economy.

The calculation for the size of surface-water drains is not difficult, the Engineer having decided on the amount of the maximum rainfall per hour and on the percentage of rainfall which will flow off the district to be drained. All the water from such of the roofs of the buildings as are not drained into the sewers, is led by eave gutters and cast-iron pipes into a house gully or discharged on to the roadside water tables or into the roadside drains, the water thence flowing to the nearest water-gully connected with an underground drain. The system of surface-water drains will naturally commence with open roadside drains or water tables, the former being constructed of sizes determined by the area and the rainfall to be disposed of.

Fig. 39 (see page 228) shews a roadside drain, 12 inches × 18 inches deep. The wall on the roadside is built of rubble masonry in lime mortar, 15 inches in thickness, while the inner wall is constructed of 4½ inch brickwork, resting against a compound wall or plinth of a house. The foundation is formed of lime concrete, and the invert of a 4-inch or a 6-inch channel pipe. The haunches are

filled up with cement concrete and the whole of the interior rendered with cement plastering. The roadside wall is built within six inches of the ground surface and is finished off with stone khankis or kerbing, 12 inches in width, 15 inches in tail, and 6 inches in thickness.

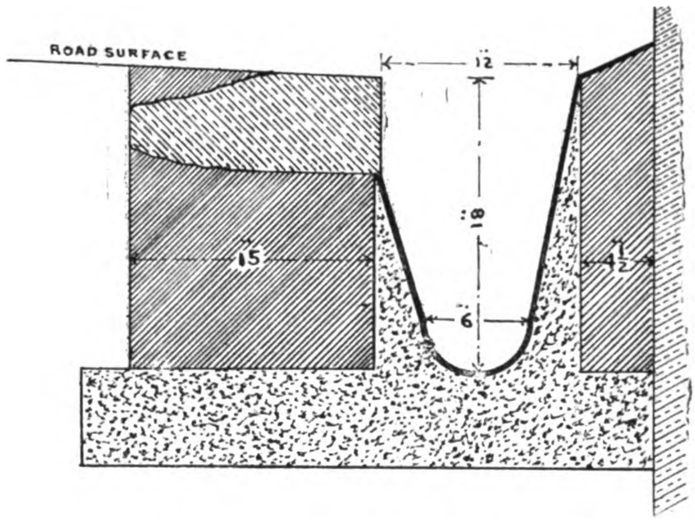


FIG. 39.

The next transition is to underground pipe drains of stoneware or cast-iron, from 6 inches to 18 inches in diameter, the next being to underground masonry drains, covered with stone slabs, 6 inches in thickness, as shewn in Fig. 40, which gives a section of a drain 2 feet by 2 feet in

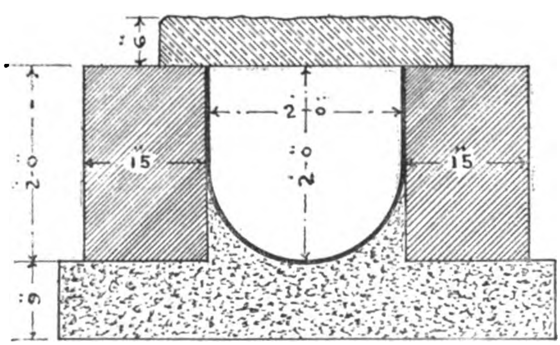


FIG. 40.

area. The foundation is laid in lime or cement concrete, 9 inches in depth, the former being used in dry, and the latter in wet ground. The walls are built of rubble masonry in lime mortar, 15 inches in thickness, and the half-round invert formed of cement concrete, the whole of the inside being rendered with cement and sand (1 to 1) ½ inch thick.

The sizes of the drains will increase in accordance with the quantity of the water to be discharged and various sizes of such drains are shewn in Plate 56.

To ensure efficient drainage, all roads and streets should be constructed with a camber of not less than 1 in 40, as shewn in Fig. 41, and the sides finished with a line of slab stones, 15 inches by 12 inches by 4 inches thick, set in lime concrete, and generally known as water

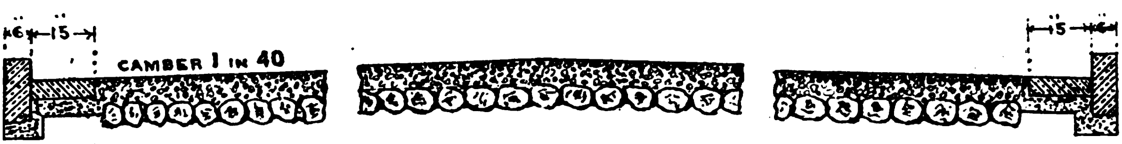
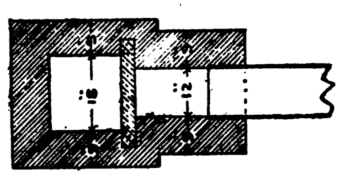


FIG. 41.

tables, on which the surface water will naturally flow. These water tables should grade each way at a slope of not less than 1 in 200 to a sealed chamber or water-gully connected with the underground surface-water drain in the road.

Fig. 42 shews a very satisfactory type of surface-water gully. It will be noticed that the trap or seal of the water gully is 9 inches; the bed of the chamber is constructed of a 9-inch layer of lime

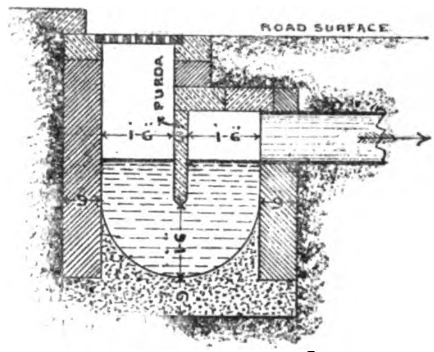
WATER-GULLY.



PLAN.
FIG. 42.

concrete, the invert being formed of cement concrete; the walls are constructed of brick-work in lime mortar, the whole of the inside being rendered with cement and sand (1 to 1) ½ inch thick; the parda or diaphragm is of blue cut-stone, smooth dressed and so fixed as to dip into the water to a depth of 9 inches and dividing the chamber into two parts; the part of the chamber nearer the underground drain is covered with 6-inch stone slabs, while the other part is brought up to the road surface, and covered with a cast-iron grating, 20 inches by 20 inches, resting on a cut-stone rebated curb, 9 inches by 6 inches. The depth of the seal of surface water gullies in India should never be less than 9 inches on account of evaporation, which so rapidly takes place in this country.

WATER-GULLY.



SECTION.

FIG. 42.

In a large city, it is very difficult to keep surface water drains absolutely free of sewage, and unless constant supervision is exercised, house connections are made to them, especially if that drain is the most conveniently situated for the house-owner, and this is an additional reason for recommending that the water seal should be so great. During the dry season it is a convenient plan to fill in all water gullies, right up to the grating, with clean sand: this allows of the road watering soaking through and passing into the drain, but prevents foul air from coming out into the street. In a general way, it is not necessary to arrange for the ventilation of surface-water drains, as, even though

the first flow of rainfall may be very foul, it is usually followed by a much clearer liquid and the deposit in the drain is usually nearly all mineral matter which will not decompose.

Fig. 43 shews a drawing of a manhole on a surface-water drain. It has been found desirable to lower the floors of the manholes as shewn in the figure. They then act as catch-pits, and facilitate the cleaning of the drain. The manhole is constructed of brick-work in lime mortar, 9 inches in thickness, the side walls resting on those of the drain and the end walls on the 6-inch dhapas. The whole of the inside of the brickwork is rendered with cement and

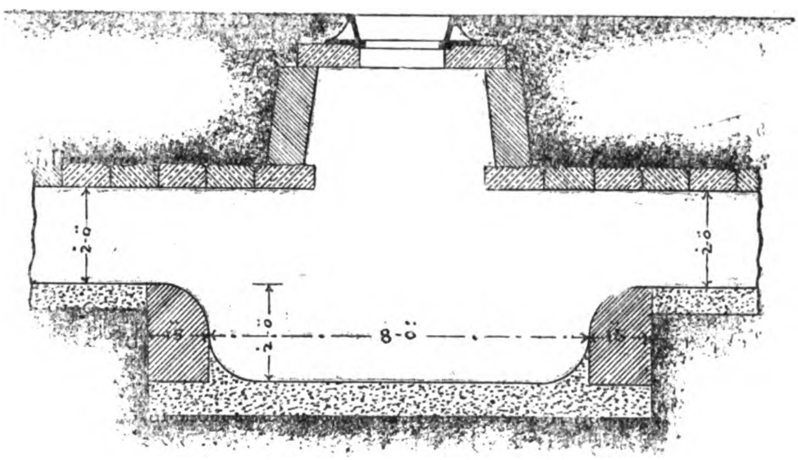


FIG. 43.

sand (1 to 1) ½ inch thick. Cast-iron steps, as before described, are inserted in one of the walls to enable the workmen to descend into the manhole. The manholes are covered with the ordinary type of covers and frames shewn by Fig. 1 on Plate 5.

The cleaning of surface-water drains is usually done by hand and during dry periods. It is not accompanied by any danger from polluted air, and therefore the rules which apply to sewer-cleaning need not all be enforced.

Sub-Soil Drainage.—The question of sub-soil drainage should always have consideration from the Sanitary Engineer, as the level of sub-soil water has much to do with the health of the community. The principal source of moisture in soil is rain, but it may arise from other causes, such as springs or excessive water-supply and wastage of the same. It is only when the sub-soil water is in excess and becomes stagnant and is close to the surface of the ground, that it becomes dangerous to health.

A saturated sub-soil prevents the circulation of fresh rain water through the soil, vegetation thereby losing the benefit. The effect of a wet or saturated soil is to reduce the temperature of the air, and is very often the cause of fogs, it is always the cause of mists arising from the ground, which are naturally injurious to health. A sub-soil of wet clay will shrink in drying about one-fifth of its bulk and swell again when wet, and for that reason buildings on such sub-soil should always have their foundations taken down below the reach of atmospheric changes: this depth in clay may usually be taken as 5 feet. Clay is a soil which is very retentive of moisture, and one cubic foot in most dry clays will absorb about one gallon of water. To get rid of superfluous water, sub-soil drainage is often necessary on sanitary grounds. If the sub-soil is composed of sand or gravel or loamy earth, then any liquid reaching the ground passes away by percolation, but this is not so in clay, which will take up moisture and retain it until it can hold no more, and any further supply of liquid remains or drains away on the surface if it can find an exit. A large proportion of the sub-soil in Bombay is clay overlying the balsaltic rock and certain low-lying parts of the Island are always wet, leading to much unhealthiness. The laying of drains and sewers generally has a beneficial effect in lowering the level of the sub-soil water, and provides a passage for it along the sides of the drain and the

sewer. It is sometimes a good plan to put a layer of road metal around the drain or sewer for the sub-soil water to flow through.

The Author has sometimes found it useful to fix in the side walls of a surface-water drain flap pipes to allow of sub-soil water finding its way in ; these pipes should not be placed below the springing line of an arched drain.

Sub-soil drains should not be less than four feet below ground level. Certain authorities recommend deeper drainage, and it is an undoubted fact that the deepest drains flow first and the longest. The filling in of old tanks is a question that crops up frequently in a large city like Bombay. Such tanks are often very deep and serve no useful purpose when a sufficient water-supply exists, but, on the other hand, they become the receptacle for all kind of rubbish and filth. Under these circumstances, they should be filled in with good clean earth and kept as open spaces; but as sub-soil water has always been flowing into the same according to the level of the water in them, in filling up such tanks a wall of coarse rubble or road metal, in which should be laid stoneware pipes with open joints, should be constructed all round the tanks, starting at a depth of 5 feet, that being about the depth at which sub-soil water ceases to be unhealthy, and the pipes graded to a point where a connection can be made with the nearest surface-water drain.

Wells abound in all large cities and their water unfortunately, no matter though it be greatly contaminated, is preferred by many Hindus to the pipe supply. The watchful control of wells is an important Municipal duty, and Health Officers are frequently called upon to take action in regard to those that are a menace to public health.

The question of filling in wells is a fruitful source of friction between the public and the authorities, and no measure of equal sanitary importance is more keenly op-

posed. The fouler the well and the more necessary its filling in in the interests of public health, the greater generally are the demands that it shall be spared, usually on religious grounds. Although the most sympathetic and respectful consideration should at all times be given to the genuine religious sentiments of the people, a limit is often reached in sanitary matters, beyond which it would be the falsest kindness to go. Many wells are found on analyses to be seriously contaminated by sewage, and to allow such to remain and spread disease, as they inevitably do, is nothing short of criminal.

Before closing this Chapter, it may be interesting to allude briefly to the first portion of the scheme now being carried out for the surface drainage of the low-lands of the Island of Bombay. The area to be dealt with is equal to 2,865 acres. To drain this, a main channel has been constructed with a bed-level at ts lower end at 71·50 T.H.D., or 6 inches below the lowest low water at spring tides. The bed slopes up from this level at a gradient equal to 2 feet per mile, and its capacity is based on a discharge of 0·70 cubic feet per second per acre, equal to 0·70 of an inch of rainfall per hour. The channel discharges into the Arabian Sea at the western foreshore of the Worli village, where sluices with four openings, each 20 feet wide, have been constructed. The channel at the lower end is 62 feet wide at the bottom, with side slopes one to one, which are pitched with dry stones. It was originally proposed to pave the bed with dry pitching, and where the foundation is hard this has been carried out; but for the main part of the channel 12 inches of lime concrete have been substituted, that having been found necessary owing to the soft nature of the ground. The main channel, which is known as Channel No. 1, runs from the Flats to Worli village and at a point near the old Worli sluices it bifurcates towards Dadar, this branch being known as Channel No. 2.

It is proposed to continue the main channel by a covered drain at Jacob's Circle, and at that point it will receive various drains from different roads in the low-lands. The same procedure will be adopted in the Dadar District.

The cost of the main work, now in hand, will amount to Rs. 13,00,000, and it is at present very nearly completed. Plate No. 57 shews the position of the channels by a thick black line.

PART II.

INTRODUCTION.

THE following accounts of the sewerage of the various cities in the East will, the Author hopes, be found interesting to the Sanitary Engineer.

In the matter of sanitation, Bombay stands out as a pattern of good local self-government, for there is no city in India, and possibly in the East, where such strides have been made in sewerage and in sanitation generally.

Most of the cities dealt with shew progress in sanitation, even from an occidental point of view; and in most cities, as in Bombay, the completion of the sewerage systems is progressing.

It is hoped that the accounts will be of use to Engineers, who have to deal with similar sewerage problems in other Eastern Cities.

Bombay is the only city that has now practically completed its sewerage works, a few outlying districts only remaining to be sewered and drained. Its position as the Gateway of India necessitates its standing first in this respect.

A few notes have been added in regard to the sewerage of Alexandria, which is not an Eastern City and some apology therefore seems necessary for its inclusion in this Book; but as the Author knows that many have condemned the inactivity of Local Governments and Corporations in the East in regard to sanitation, he thinks that the following notes will shew that there is no city in the East, with any pretensions to being a city, that cannot hold up the finger of scorn to Alexandria in the matter of sanitation. It is a large and important city with great natural advantages, lying on the border-land of Europe; and in spite of its increasing importance, it has spent practically nothing in improving its sanitation for the last thirty years, wnile, refusing advice and warning, it has persisted in neglecting the first rudiments of sanitation.

CHAPTER VIII.

SEWERAGE OF BOMBAY.

THIS book would hardly be complete without a short history of the drainage of Bombay, for there is no city in India, and possibly in the East, where such strides have been made in sewerage and in sanitation generally. Many races of the world are represented there, each with its own distinctive domestic customs, and the condition of drainage are therefore varied and uncommon.

The history of the drainage of Bombay is as interesting as it is exceptional, and if, in the light of later experience, it has been found that mistakes have been made, it must be remembered that even so recently as twenty years ago, sanitation was to a great extent empirical and the system of "trial and error" had inevitably to be largely resorted to. Devious although the approach may have been, there is little doubt that Bombay has now arrived at a satisfactory scheme, a study of which, with its great variety of circumstances, must prove of the highest instructive value.

Plate 58 is a copy of an old plan of Bombay as it existed in the year 1672, when it consisted of seven separate islands, which have all now disappeared as such, owing partly to the action of nature, but mostly to the work of man. The red boundary in the plate shews the Island as it exists at the present time. It will be seen that a more difficult place could hardly be found for drainage purposes than this city, with its large area of reclaimed ground below high-water level.

The population of Bombay in the latter part of the seventeenth century is recorded as only 60,000, and the various islands are known to have been inhabited by people belonging mostly to the fisher caste: many traces of old fishing villages and the descendants of the people themselves still remain in parts of the city.

During the period from 1672 to 1845, in which year the Municipal interests of the city were entrusted to a Board of Conservancy, much was done towards reclaiming the spaces between the islands. There was, however, left for drainage purposes an open ditch, known as the old main drain, which ran from where the Crawford Market now stands, *via* Abdul Rehman Street, Paidhoni, Bapu Khote Street, and Falkland Road, to the Flats, where it emptied itself into a tidal estuary. No attempts were made to arch over any portion of this drain until 1824, and it was not until 1845 that it was covered even as far as Paidhoni, though the progress after that was comparatively rapid, and by 1856 the arching had been completed up to Bellasis Road.

The size of this old main drain varied. At its commencement in Abdul Rehman Street it was 2 feet by 2 feet. After passing Paidhoni its size was much increased, no doubt because of cross-drains running into it, it being at that point 10 feet 9 inches wide by 4 feet high with a gradient of 1 in 450. In Falkland Road its size was further increased to 20 feet 3 inches by 8 feet 6 inches with a gradient of about 1 in 5,000. In Bellasis Road, where it received the drainage of that part of the island even then known as Byculla, its size was 20 feet 3 inches by 9 feet 10 inches, with a gradient of about 1 in 1,140. From this point it ran over the Flats to the sluices in an open cut. The arching consisted, for the most part, of roughly-dressed stone with side walls of the same material. In many parts there was no foundation, but where any existed it was of

rough rubble. This drain carried all the surface water in the monsoon, and all the year round such sewage as was discharged into it by gravitation or by hand. The state of sanitation must, indeed, at this time have been serious, considering the flat gradients and defective construction of the old main drain. It must have been a vast elongated cess-pool, and probably always contained a large quantity of putrefying sewage. This old main drain exists even to this day, though much improved by having been repaired and in parts re-built. It is, perhaps, needless to add that it is now used for storm-water only.

Things had become very serious by 1853, when Mr. Conybeare, a "Superintendent of Repairs," submitted a plan to the Board of Conservancy for alleviating the nuisance resulting from the old main drain. His plan provided for no alteration to the condition of things during the monsoon, but during the dry weather it was proposed to run the sewage into a pit near Bellasis Road and to lift it after deodorization and use it for irrigation on the Flats. It is on record, and this is hardly surprising, that this did not improve, but rather intensified, the nuisance. Things continued much in the same way until 1860, when a scheme for the drainage of the city was submitted by Mr. Tracey, the Municipal Engineer, who seems to be the first Engineer who seriously attempted to deal comprehensively with the whole of the drainage of the city. He objected to the application of sewage to land, and proposed its discharge by two outfalls into the harbour. In his proposals Mr. Tracey objected to an outfall on the west, as being the windward side, and because he saw the risk of sewage deposit on the foreshore.

The scheme, briefly speaking, provided for the discharge of the sewage at two points, viz., Wari Bunder and Carnac Bunder. It was proposed to discharge the sewage of Umerkhadi, Girgaum, Kamatipura, Tarwadi, and Now-

roji Hill at the former outfall, and that of the Market, Mandvi, and Sonapur at the latter. At Carnac Bunder all the sewers were to discharge into the sea by gravitation only. At Wari Bunder there was to be a low-level as well as a gravitation system. The low-level sewers were to discharge into tanks, whence the sewage was to be pumped into the harbour at ebb-tide. The sewers on the gravitating system were designed to carry both sewage and storm-water, but from the low-level sewers, storm-water was excluded. The whole scheme was to cost Rs. 33,20,000.

Mr. Tracey's scheme was sent to England to the Secretary of State, and Mr. Robert Rawlinson, afterwards Sir Robert Rawlinson, K.C.B., was asked to report on it. Mr. Rawlinson reported favourably in 1863, with some slight modifications. It was accordingly sanctioned by Government in September 1863, and Mr. Tracey was appointed to carry it out, with Captain Trevor as Consulting Engineer. But before much work could be done, Mr. Tracey unfortunately died, while Mr. Wilcox, his Assistant, who succeeded him, also died shortly after.

In the meantime, an agitation was got up against the propriety of placing sewage outfalls so near the populated parts of the City, and Government appointed a Commission, of which Mr. T. Ormiston, the first Port Trust Engineer, was a member. Mr. Ormiston was of opinion that Colaba was the best point for the discharge of the sewage (a view that is now very generally accepted as correct), and that storm-water and sewage ought to be separated, and Government concurring with these views condemned Mr. Tracey's proposed outfalls.

For a year or two no further steps were taken, and the next important epoch in the history of the drainage of Bombay was the scheme prepared in 1866 by Mr. Russel Aitkin, then Engineer to the Municipality, who proposed that the sewage should be discharged into a reservoir at

Colaba near the Lighthouse and pumped into the sea on the ebb-tide. Mr. Aitkin objected to a "separate system" as impracticable in Bombay, and therefore provided for the sewage and the storm-water to flow away by the same drains. He proposed a main sewer from Null Bazar to Colaba with large branch sewers from different districts. These intercepting sewers were designed to carry a maximum rainfall of eight inches per diem in addition to the ordinary sewage of the districts to be drained. During the fair season the sewage was to flow by the main sewer to Colaba where it was to be pumped into the sea. During the monsoon the branch sewers were to be cut off from the main sewer, and to discharge the sewage and storm-water into the harbour or Back Bay, the flow being against the gradients. The main sewer from Null Bazar to Colaba was thus during the rains to carry off the sewage and storm-water only from the low-lying district lying between Khetwadi and Bellasis Road. This main sewer was designed to carry off only two inches of rainfall per diem from this low-lying district, and Mr. Aitkin therefore proposed to retain the existing open main drain to receive the surplus, when more than two inches of rain fell in a day.

The whole cost of Mr. Aitkin's scheme was 110 lakhs of rupees, the annual working expenses being Rs. 2,50,000. Mr. Russel Aitkin's views at that time regarding the velocity in the sewers strike one as curious in these days of advanced knowledge. In the main sewer the velocity was to be not more than 2½ feet per second when running full with sewage and storm-water, but during the dry weather it was to be only 1 foot or even 9 inches per second, and this was then supposed to be sufficient to prevent deposit in the sewers.

In 1867 Mr. Aitkin's scheme was forwarded to Mr. Robert Rawlinson, who was of opinion that sewage discharged at Colaba would return to the harbour. The na-

tural fall of the Island towards the Flats and Warli indicated to him the true direction for the conveyance of the sewage. He further added that float experiments carried out by one Mr. Jagannath Sadashiv proved that a Colaba outfall would contaminate the harbour.

As regards these float experiments, which were believed in and relied upon for so many years as conclusive evidence that to discharge the sewage at Colaba would be fatal to the interests of the City, it is interesting to note that it was left to Mr. Baldwin Latham during his visit to Bombay in 1890 to discover that the arrows indicating the directions of the floats were wrongly shewn on the plan. That is to say, they pointed to the north instead of to the south and thus erroneously led to the conclusion that the current during the ebb-tide set into the harbour instead of flowing to the open sea. This extraordinary mistake has no doubt been the principal cause of Bombay having its outfall on its western foreshore with all the nuisance that has arisen therefrom.

Mr. Russel Aitkin's scheme, therefore, remained in abeyance, though some works proceeded in the Fort which had its separate outfall near the Mint.

Pending the settlement of the main question of the drainage of Bombay, Mr. Aitkin also constructed a low-level sewer from Bellasis Road to Love Grove, which during the fair season intercepted all the sewage from the old main drain, and conveyed it to a Pumping Station at Love Grove, where it was lifted by one chain and two centrifugal pumps into the sea. The drainage of Kamatipura was also taken in hand, and brick-sewers and pipe-sewers were substituted for open drains. These sewers, though highly commended then, were afterwards condemned by Mr. Baldwin Latham in 1890.

In 1868 Captain, now Major, Tulloch came to Bombay from England, and the Municipality referred the drainage

question to him. In November 1868, he submitted his report and advocated the segregation of sewage from storm-water and was of opinion that whether the sewage was applied to land or discharged into the sea, it should be taken towards the west of the city and not towards the harbour or Colaba. His reasons were that the natural slope of the Island was towards the west, and any discharge towards the east might foul the harbour.

He proposed to pump the sewage at Love Grove and to utilise it on land, or, as an alternative, to carry it back from Love Grove and discharge it at Colaba, if an outfall at that point were approved, though he was personally opposed to this. He was equally opposed to an outfall on the west, but ultimately his own reasoning in meeting the arguments of the opponents to his scheme led him inevitably to that point.

In 1869, Government appointed a Commission, with Mr. A. R. Scoble as President, to consider and report on the drainage and water-supply of Bombay, including a report on Major Tulloch's scheme.

The Commission concurred with Major Tulloch as regards the necessity for a "separate system," but they differed from him on several points, principally the carrying of the night-soil through the sewers and the utilisation of sewage on land.

Plate 59 shews an interesting geological map of the Island of Bombay prepared by Major Tulloch in support of his proposals to carry the main sewer towards Love Grove, that course running for the most part through made ground.

The report of the Commission, and the financial difficulties in which the Corporation found itself at the time, postponed any serious advance being made with the drainage until 1877, though during the interval some work was done, slowly and casually, as particular nuisances required to be dealt with.

The extension of building operations, however, aggravated the nuisances, and in 1877 they became so intolerable that on the recommendation of the Town Council, the Corporation asked Government to appoint a Commission to advise as to what scheme was the best to adopt for the drainage of the City, and Government responded by appointing four gentlemen with Surgeon-General Hunter as the President. A number of witnesses were examined by the Commission, which issued its report in January 1878, recommending the adoption of Major Tulloch's scheme as slightly modified by Mr. Rienzi Walton, the then Executive Engineer to the Municipality, who advocated the pumping of the sewage into the sea at the Love Grove outfall. This scheme consisted of laying a main ovoid sewer from Carnac Bunder to the Crawford Market to be continued along Sheik Memon Street, Bhuleshwar, Khetwadi, and the Flats to Love Grove, with a branch sewer from the Town Hall to the Crawford Market and another up Clerk Road. A Pumping Station was to be erected at Love Grove to pump the sewage into the sea. The Commission was further of opinion that house-connections would be suitable, and that provided the water-supply was not less than 20 gallons per head per diem, the night-soil might be freely admitted into the sewers, with a recommendation for the enforcement of a standard water-closet, except for huts and inferior buildings where house-connections were impossible. It stongly recommended free ventilation of all sewers, and the separation of storm-water from sewage.

The drainage of Bombay, as now carried out, has in the main closely followed these recommendations.

The report of General Hunter's Commission was an important one, as it marks the commencement of an entirely new era regarding the drainage history of Bombay.

The Corporation took the matter up seriously and in March 1878 sanctioned the scheme. The Government of

India were asked to give a loan of Rs. 60 lakhs, most of which was to be devoted to its execution. The loan was refused, and in September 1878 the Municipality itself raised a loan of 27 lakhs in Bombay, and in December of the same year the work was commenced under the supervision of Mr. Rienzi Walton, the Executive Engineer, who was placed on special duty for this purpose. The works immediately taken in hand were the main sewer from Carnac Bunder to Love Grove, certain branch pipe sewers, a Pumping Station with new plant at Love Grove, and a new outfall sewer.

In May 1881 the main sewer, as it now exists from Carnac Bunder to Love Grove, was completed. It is ovoid in shape and of the following sizes:—

From	To	Sizes.	Distance in Miles.
Frere Road (Carnac Bunder).	South end of Sheik Memon Street.	2′-6″ × 3′-9″	0·52
South end of Sheik Memon Street.	Cawasji Patel Street.	2′-8″ × 4′-0″	0·78
Cawasji Patel Street.	Junction of Khetwadi Back Road and Khetwadi 10th Lane.	3′-4″ × 5′-0″	0·51
Junction of Khetwadi Back Road and Khetwadi 10th Lane.	Junction of Grant Road and Falkland Road.	3′-10″ × 5′-9″	0·14
Junction of Grant Road and Falkland Road.	Clerk Road Crossing.	4′-8″ × 7′-0″	0·35
Clerk Road Crossing.	Love Grove	5′-4″ × 8′-0″	0·95
		Total ...	4·25

The cost of the whole of this work amounted to five lakhs of rupees.

By 1880 the outfall sewer from the Pumping Station to an out-let chamber on the foreshore had been completed at a cost of 2½ lakhs. This is a double barrelled masonry sewer, each barrel being 3 feet 6 inches in diameter. From the chamber are laid two parallel 36-inch pipes, running into the sea 6 feet below low-water spring tides. These pipes were not laid until the end of 1881.

Meanwhile branch pipe sewers had also been laid, connecting with the main sewers, in various streets, at a cost of 2½ lakhs.

The Pumping Station at Love Grove has a history of its own. The first was erected, as already stated, in 1867 by Mr. Russel Aitkin and contained two centrifugal pumps and a chain pump. In 1869, the flow of sewage was considerably increased, and in 1870 two new chain pumps were erected and one of the old centrifugals removed. In 1872, a further alteration was made, the other old centrifugal pump being removed and a new direct-acting centrifugal pump put in its place. The four pumps, namely, three chain pumps and one centrifugal, were together capable of lifting 20½ million gallons per diem, though not more than 8 million gallons per day found its way to the pumping station. From time to time, the pumps gave trouble, and finally it was decided to erect a new Pumping Station and plant, which was included as a part of Mr. Walton's scheme sanctioned by the Corporation in 1878. The new station was completed in 1884 at a cost of a lakh of rupees, and four engines and pumps were erected therein at a further cost of a lakh and three-quarters. These engines and pumps worked until 1890, when they were condemned by Mr. Baldwin Latham as being extremely inefficient and thoroughly worn-out. A new engine-house was then constructed near the old one, and four Worthington direct-acting triple-expansion engines and pumps made by Messrs. James Simpson & Co., London, capable of lifting 15 million

gallons each per diem, together with four Babcock and Wilcox boilers, were erected at a cost of four lakhs of rupees.

These commenced to work in 1893, and are still doing their work efficiently.

It has already been stated that brick and pipe sewers were laid in Kamatipura by Mr. Russel Aitkin, and in 1870 the district was declared by Mr. Thwaites, who succeeded Mr. Aitkin as Engineer, as one of the best drained districts. In 1877, however, the attention of the Corporation was directed to the insanitary state of the district and Mr. Walton was asked to report on it. Mr. Walton reported in 1880 that the system of drainage in Kamatipura was a complete failure: the joints of the pipe sewers were made of clay, storm-water and sewage were discharged into the same channels, and the brick sewers were directly connected with the old unventilated Umerkhadi sewer. He submitted a scheme for the re-sewerage of Kamatipura, which provided for the re-laying of the pipe sewers and connecting them with the new main sewer at the junction of Grant Road and Falkland Road by means of a new 2 feet 6 inches by 3 feet 9 inches branch ovoid sewer. It also provided for the exclusion of all storm-water from the sewers. The scheme was approved and sanctioned at a cost of a lakh and a half of rupees, and the works were completed in 1883.

In the same year a branch ovoid sewer, 2 feet 6 inches by 3 feet 9 inches, was constructed along Clerk Road from the main sewer to Jacob Circle at a cost of Rs. 30,000, which was in the next two years extended to opposite the Victoria Gardens at a further cost of Rs. 33,000.

In 1885, the Queen's Road sewer, which runs from opposite the B. B. & C. I. Railway Marine Lines Station and joins the main sewer at Khetwadi 10th Lane, was completed at a cost of a lakh and a half of rupees. This sewer

intercepted all the sewage which was being discharged into Back Bay.

Other drainage works were also at this time pushed on rapidly, the Ripon Road ovoid sewer, 2 feet 6 inches by 3 feet 9 inches, having been completed in 1886 at a cost of Rs. 60,000 ; the Mint Road sewer, also 2 feet 6 inches by 3 feet 9 inches from the Mint to the Crawford Market, was completed in the same year at a cost of Rs. 90,000 ; and, in 1890, the pipe sewers in Agripada were laid at a cost of one lakh.

House connections were also pushed forward in various districts, the Corporation spending some fifteen lakhs of public money on these connections.

In 1889, complaints were received of nuisances existing in Marine Lines—a part of the City principally occupied by the Military—and the same being attributed to the new pipe sewer, Government appointed a Committee to inquire into the matter. The Sanitary Commissioner to Government, who was one of the Committee, made an adverse report on the sewerage of the City generally ; considerable discussions also arose as to the suitability of the sewage outfall at Love Grove; and the Corporation, on the recommendation of Sir Charles Ollivant, the then Municipal Commissioner, sought the advice of Mr. Baldwin Latham on the question of the drainage of the City, both present and future.

Mr. Latham came to Bombay in 1890, whose visit was a very successful one and resulted in the Corporation obtaining a useful report known as the "Sanitation of Bombay." He reported that the different sections of the main sewers were properly designed in regard to the population they were intended to serve, but that he found considerable silt in them, mostly due to the inefficiency of the pumping engines at Love Grove, which he condemned as

worn out. He found that the pipe sewers had been well laid, and pronounced the jointing equal to any he had seen elsewhere. He condemned the outfall at Love Grove and shewed the fallacy of the float experiments of Mr. Jagannath Sadashiv and proved that an outfall at the Colaba point was the best. As, however, the main sewers had already been laid with a fall towards Love Grove, he recommended that all the sewage should first flow to Love Grove and be there pumped into a high-level gravitating sewer running from Parel to Colaba and discharged at the latter place at ebb-tide only beyond the Prongs Light House.

The Corporation sent a copy of the report to Government to ascertain if they would allow an outfall at Colaba as recommended by Mr. Latham. The Government appointed a Commission who examined, among other witnesses, Mr. Baldwin Latham, who admitted that if, for financial or other reasons, the outfall could not be placed at Colaba, the existing outfall was the next best. The Commission reported that the cost of Mr. Latham's proposals was prohibitive, and that Love Grove was the second best site for an outfall, and the Government declined to sanction the new proposals.

In 1893, although a large amount of the island had been drained, there still remained several populated parts of the City where no drainage of a satisfactory kind existed. These districts were Colaba, Mazagon, Malabar Hill, Chinchpokli, Parel, and the northern part of the Island.

Colaba was the first of these districts to engage the attention of the Municipality. The discharge of sewage at different points into the harbour created an intolerable nuisance, and loud complaints were made by the public. It could not, however, owing to the configuration of the land, be drained by gravitation only to the sewers already laid, and some sectional system had therefore to be resorted

to. It was at first proposed to lift the sewage at some convenient point by direct-acting pumping, but the Municipality failed to obtain any suitable site for a pumping station. Both the Port Trust and the Government, who are large land-owners in the district, declined to give land for the purpose. After great discussion, it was ultimately decided in 1893 to drain the district on the Shone System. The works were designed and carried out by the late Mr. J. W. Smith at a cost of eight lakhs of rupees. They provide for a prospective population of 28.000 people, the present population being about 18,000.

The district is divided into five blocks, each having an Ejector Station as shewn in Plate 60.

Nos. 1, 2, and 3 Ejector Stations have each two ejectors of 500 gallons capacity each, No. 4 Ejector Station two ejectors of 300 gallons capacity each, and No. 5 Ejector Station, two ejectors of 100 gallons capacity each. One ejector is sufficient to cope with the sewage in each block, the other being held in reserve. The stations are built of bricks set in cement mortar, plastered on both sides with cement.

The compressed air is supplied to the ejectors from an Air Compressor Station, erected in a convenient position near the Arthur Basin. In this are placed three compound non-condensing engines, each of 40 indicated horse-power, with two marine boilers of the type known as the "Dry Back Tubular." Two engines and one boiler are sufficient to deal with the maximum requirements of the whole district, the third engine and the other boiler being a stand-by. Each of the engines is designed to deliver 450 cubic feet of free air per minute, compressed to 22 lbs. above atmospheric pressure.

The compressed air is delivered into an air-receiver, placed outside the engine-house, having a capacity of 800 cubic feet. The air main is coupled up to the receiver, and

supplies air to each of the stations by means of suitable branch pipes.

A sealed sewage main is laid from No. 3 Ejector Station to the Wellington Fountain at the north end of the Colaba district, with branches from Nos. 1 and 2 Ejector Stations. and discharges into a long chamber near the Fountain. From this chamber the sewage flows into the gravitation pipe sewers. The use of the chamber is to receive the contents of the sealed sewage main, should they be required to be suddenly blown out in the case of an obstruction taking place in the main. No. 4 Ejector Station discharges its sewage through a short length of sealed sewage main into the head of a sewer gravitating to No. 3 station, where it is all re-lifted, while No. 5 discharges also through a short length of sealed sewage main into the sewer gravitating to No. 4, where the sewage is re-lifted and sent to No. 3, where it is again re-lifted. The double lifting of the sewage of No. 4 sub-district and the treble lifting of that of No. 5 has been adopted as being economical, for the reason that to force the sewage of these sub-districts, which is comparatively small in quantity, through a rising main from one end of Colaba to the other, would require compressed air at a much higher pressure than necessary for the other three stations, where the greater part of the district gravitates.

The drainage of this district was completed in 1895, and house-connections were immediately taken in hand, not on this occasion at the cost of the Corporation, but of the owners themselves, and completed in the following year.

The Shone System at Colaba gave such satisfaction that it was decided in 1897 to extend the system to other districts, *viz.*, Mazagon, Parel, Chinchpokli, the Old Race Course, and Malabar Hill.

It was considered more economical to provide at one station the air compressing machinery required for all

these districts than to construct separate installations for each of them. The Corporation, therefore, sanctioned in 1897 the construction of an Air Compressor Station at Love Grove to the north of the Pumping Station, and the erection of the air compressing machinery and the laying of air mains capable of dealing with the sewage of all the above districts, at a cost of 8 lakhs.

Simultaneously with this work, the sewerage of the Mazagon District was also taken in hand. Here two ejector stations have been constructed at the positions shewn in Plate 61, one containing two ejectors of 1,200 gallons each and the other two of 250 gallons each. In this district the ejector stations have been built of cast-iron tubbing, owing to the presence of much subsoil water. The work was completed in 1899 at a cost of 3½ lakhs.

In 1900-1901, a further extension of the Shone System was sanctioned for the districts of Chinchpokli and Parel. There are two ejector stations in the former district, and three in the latter. Plate 62 shews the positions of the five ejector stations, and the pipe sewers, air mains, and sealed sewage mains.

Ejector Station No. 1, in the Chinchpokli District, is built of brick-work in cement and contains two ejectors of 1,000 gallons each, while that in No. 2 is of cast-iron tubbing, containing two ejectors of 1,200 gallons each. The ejector stations Nos. 1 & 3 in the Parel District are brick chambers, while No. 2 is of cast-iron tubbing. No. 1 station contains two ejectors of 700 gallons capacity each, No. 2 contains two ejectors of 1,000 gallons capacity each, and No. 3 contains two ejectors of 600 gallons capacity each. The compressed air is supplied to these stations from the Air Compressor Station at Love Grove. All the sewage is discharged into existing gravitation sewers and flows to the Pumping Station at Love Grove. The cost of sewering

these two districts has been about 9 lakhs. and the works were completed by the middle of 1903.

There now remains only the drainage of Malabar Hill, the Elphinstone Estate, the Agripada Estate, and the North of the Island.

The Agripada and Elphinstone Estates are to be drained on the Shone System, the compressed air being supplied from the present station at Love Grove. Each district will have two ejector stations, with duplicate ejectors in each. The work of sewering the Agripada Estate has been sanctioned, and is now in hand.

As regards Malabar Hill, the proposals are to deal with half the sewage on a biological system, to drain about a third of the district to the north on the Shone System, and the remainder near Chaupati by low-level sewers and a small pumping plant.

Plate 63 shews the three divisions of the district and the drainage arrangements in each sub-district. No. 1 is that which is to be drained on the biological system, the purified sewage being discharged at once into the sea. The prospective population is taken at 8,000 and the daily flow of sewage at 300,000 gallons. The sewage is to first flow into a closed Liquefying Tank having a capacity of one day's flow of sewage. This tank will be 160 feet by 50 feet by 6 feet, and so constructed that it can be cleaned in sections. Connected with the tank will be duplicate catch-pits and screening chambers to arrest such materials as rags, road detritus, and other mineral matter in the sewage. The effluent from the Liquefying tank will flow on to a series of 6 contact beds for its final purification, each of the beds being 110 feet by 32 feet by 3 feet. These beds will be filled with 1 inch cube metal. Besides further purifying the Liquefying Tank effluent, the contact beds will serve also as a storage tank when the tide is above the level of the beds. The installation is to be built on the

Western Foreshore with a wall protecting it from heavy seas. It is proposed to utilise the gas from the Liquefying Tank for lighting the installation at night and also for burning the screenings from the sewage.

No. 2 sub-district is to be drained on the Shone System, an ejector station containing two ejectors of 250 gallons capacity each being placed in Warden Road near Scandal Point. The compressed air will be supplied from Love Grove and the sewage lifted and discharged into an existing gravitation pipe-sewer, a few hundred feet to the north of the ejector station.

The sewers in No. 3 sub-district will gravitate to a point on the Chaupati Estate, where the sewage will be lifted by means of an oil engine and pumps into a gravitation sewer.

The total cost of drainage of the three sub-districts is estimated to be:—

Sub-district	No. 1	Rs.	3,19,439
Do.	" 2	"	1,99,635
Do.	" 3	"	1,20,874
	Total	Rs.	6,39,948

It may be noted that the cost of sewering the whole of the district on the Shone System, as originally intended, was estimated to cost Rs. 7,71,190 or Rs. 1,31,242 more than the above estimate.

The sewage work in No. 1 Sub-District was sanctioned in 1903, but owing to certain technical difficulties the actual carrying out of the work was not taken in hand until the latter part of 1904. The work, however, has been rapidly expedited and will probably be now completed in a few months. The sewerage work of No. 2 and No. 3 sub-districts has also been recently sanctioned and arrangements have been made to proceed with the same.

With regard to the drainage of the north of the Island, the scheme proposed is to dispose of the sewage of three villages—Wadala, Gowari, and Khara—lying to the east of the ridge, by biological treatment and a sewage farm. It is impossible, owing to the position of these villages, to drain them to the Love Grove Pumping Station without some scheme of local pumping, and the initial and annual recurring expenses involved in such a scheme would be out of all proportion to the importance of the villages. It is, therefore, proposed to drain them by open drains and pipe sewers to a sewage farm after passing the sewage through an Open Liquefying Tank. Open drains have been adopted in part of the scheme, owing to the difficulty of obtaining self-cleansing gradients for closed sewers. At the junction of open drains with pipe sewers, storm-water over-flows will be provided, which will pass all domestic sewage in the fair weather from the open drain to the sewer, but, in the rains, will discharge rain water and diluted sewage into storm-water drains. Sewage should not, however, be allowed to pass into storm-water drains or ditches, unless diluted with at least six times its volume of rain water.

The population is taken at 4,000, 20 gallons of sewage per head per diem being provided for.

The buildings in these villages are for the most part one-storied and can be more aptly described as huts than houses; it is, therefore, proposed to avoid house connections as far as possible, and provide public latrines and washing places at different points.

It is further proposed to acquire for the farm sixteen acres of land to the east of the Matunga Leper Asylum. The Liquefying Tank will be of sufficient capacity to hold three-quarters of one day's dry weather flow, and the sewage will be passed through a screening chamber and a catch-pit before entering the Tank. The effluent will be conveyed on to the farm by suitable carriers.

The crops to be grown on the farm will be guinea grass, kurby, jowar, and different kinds of vegetables. Quarters will be provided at the farm for the supervising staff and the malis.

The cost of these proposals is estimated at Rs. 2,12,426.

This scheme should not only afford a satisfactory solution of the problem of the drainage of such villages, but should also be financially a paying one. If this expectation is realised, other similar out-lying villages in the north of the City will probably be similarly dealt with.

Another proposed drainage scheme is for the village of Dharavi, situated in the extreme north of the Island. Dharavi is principally inhabited by employes of the various tanneries situated in the village, and by a colony of fishermen. There are some fifty tanneries and the daily amount of sewage from these is 330,000 gallons. The population is about 6,000 and with 20 gallons of water per head per diem, the amount of domestic sewage will be 120,000 gallons per day. It is not possible to drain the village on a gravitation system to Love Grove, and sewage containing so large a proportion of tannery waste cannot be treated biologically. It has, therefore, been decided to discharge the sewage on the ebb-tide into Mahim Bay, after passing it first through precipitation tanks, and, if necessary, chemically treating it with alumino-ferric. Chemical treatment will not be tried in the first instance but will be adopted, should ample screening and precipitation prove inefficient. There will be three outfalls to which the sewage will be conveyed for the most part by open drains, the configuration of the district making it impossible to drain the whole village by gravitation to one outfall ; and even with three outfalls the levels would not allow of closed drains being wholly laid.

At each outfall a precipitation tank, capable of holding three hours' dry weather flow, will be constructed, and the sewage will be screened through sloping screens in its passage into the precipitation tank. In order not to foul the foreshore of Mahim Bay, the discharge of sewage will be only on the ebb-tide and storage tanks will therefore be constructed in connection with the precipitation tanks. The storage tank at each outfall will be capable of containing 75% of the estimated dry weather flow of sewage discharging at that outfall. Plate 64 shews the arrangement at one of the outfalls.

As in the case of the villages of Wadala, Gowari and Khara, so also in this case house connections will be avoided, public latrines and washing places being constructed at certain places.

The total cost of the scheme is estimated at Rs. 1,75,000.

Plate 65 shews the parts of the Island drained on the gravitation system and those on the Shone System.

Nothing has yet been finally decided as regards the drainage of the other parts of the north of the Island, but the consideration of this must, of necessity, force itself on the authorities in the next few years, as the City is gradually extending in that direction.

In the autumn of 1899 the late Mr. W. Santo Crimp, at the request of the Corporation, visited Bombay to advise on the various drainage questions, particularly that of the disposal of the surface-water of the City and that of the discharge of sewers at the Love Grove outfall. For a long time loud complaints had been made by the public regarding the sewage discharged at the Love Grove outfall, the smell being perceptible, particularly at the time of the ebb-tide, all along the western foreshore of the Malabar Hill. The history of the outfall has been touched upon in

the early part of this chapter, where it has been pointed out that a small clerical error has been the cause of years of trouble and nuisance to a part of the Island which should have been, in regard to its healthy condition, the most desirable residential quarter of the City.

Mr. Santo Crimp caused a series of float observations to be taken at Love Grove, the results of which are very interesting and are shewn in Plate 66. They show without doubt that the sewage discharged on an ebb-tide flows on the surface of the sea and is carried by the tide well down and towards the coast in the direction of the Malabar Point. On the other hand a flowing tide took the floats well out into the sea and up the coast.

The following remedies have been proposed by Mr. Santo Crimp to overcome the nuisance during the ebb-tides:—

(1) The extension of the present outfall into deeper waters;

(2) Treating the sewage discharged during the first four hours of the ebb-tide with electrolyzed sea-water;

(3) Treating the sewage discharged during the first four hours of the ebb-tide with Permanganate of Potash;

(4) An extension of the outfall sewer to Worli Point, discharging at that point all the sewage during ebb-tide, and at the Love Grove outfall during the flowing tide.

The first remedy proposed is now impracticable, and of the remainder the fourth is probably the most economical and satisfactory.

While the Author was in England in 1903, he was deputed by the Bombay Corporation to visit several Disposal Works in England and to submit his views on the question

of abating the nuisance arising from the Love Grove Outfall. He visited several towns and cities in England and submitted a report to the Corporation, giving an account of the Disposal Works at those places, and expressing his views on the particular question at issue.

He pointed out that while in all well sewered towns in England, with a sea outfall, crude sewage is discharged into a depth of water not less than 18 feet and at a great distance from the shore, the present outfall at Bombay discharged nearly 30 millions of gallons of sewage per diem into a minimum depth of 6 feet of water and close to the shore.

He gave it as his opinion that if the sewage were chemically treated and precipitated, no alteration in the present outfall would be necessary; but he at the same time pointed out, on the basis of experiments carried out at Manchester, that the cost of the chemicals was prohibitive. The expenditure on the cheapest chemical material viz., Chlorine, would in Bombay, on the Manchester basis, be 26 lacs of rupees per annum. He also pointed out that there was no way of simply deodorizing the sewage of Bombay. In all cases where sewage is chemically treated in the British Isles, it is done to precipitate the solids, and to that extent deodorization is combined with it, but in no case is deodorization alone performed.

The Author, on these considerations, put forward another remedy as worthy of attention to abate the nuisance in question.

There is no doubt that the foulness of the Bombay sewage is mainly due to the masses of night-soil thrown into the sewers at certain parts of the City. The Author pointed out that if the night soil were not discharged into the sewers, the existing outfall at Love Grove could be maintained in its present condition without causing any

particular nuisance. It was therefore suggested that the night-soil should be pressed into sludge cakes at various depots. These cakes could then be either incinerated or disposed of by tipping into some low-lying area outside the populated districts. The initial cost of this proposal was estimated at about Rs. 90,000.

It will be seen from this description that the Drainage of Bombay presents an exceptional variety of different systems, and accordingly there can be few cities, if any, in India of greater interest or higher educational value to students of sanitation. The ignorance and indifference of former times in sanitary matters are now happily well nigh things of the past, and in Bombay the leading citizens have for many years taken a keen, helpful and most intelligent interest in sanitation and kindred matters. The last nine years of plague have taught many lessons, not the least valuable and far reaching of which is the appreciation of cleanliness and sanitation, which seems to be now becoming general even among the humblest.

CHAPTER IX.

SEWERAGE OF CALCUTTA.

The City of Calcutta is situated in the lower Gangetic delta, on the east bank of the river Hoogli in latitude 22°33′ 47″ N. and longitude 88°23′ 34″ E. The name Calcutta appears to have been corrupted from Kali, an aboriginal Hindu goddess.

The City was founded in 1690 by Job Charnock, a merchant of the East India Company, who, with his associates, considered the site sufficiently above the surrounding swamps to be suitable for a settlement. The visitors, anticipating trouble, soon built a fort named Fort William (in which was situated the historical Black Hole) to protect their property; and the present magnificent City gradually developed round the site. No vestige of this fort now remains above ground. A new Fort William has been built further south. The "City" Port dues in the year 1700 were about Rs. 500. The value of its import and export "sea-borne foreign trade" in 1900-1901 amounted to 3,179 lakhs and 5,400 lakhs of rupees respectively. Its revenue in 1694 was Rs. 900; it is now (1905) nearly 69 lakhs.

In 1727 a Corporation of nine Aldermen and a Mayor was appointed to look after the Municipal affairs of the Settlement, but appears to have done little for its sanitation, for in 1870 we are told that Calcutta was little better than an undrained swamp with filthy roads and streets, and with drains and ditches reeking with putrifying matter.

Between 1794 and 1836 it was the custom to raise funds for the improvements of the town by means of lotteries, 10 to 12 per cent. of the amount collected being retained for improvement works and expenses, the rest being distributed in prizes. From 20 to 30 lakhs of rupees were obtained in this manner. New roads were constructed from the north to the south of the City and from the east to the west, until in 1836 the total length of roads reached 170 miles. A Pumping Station was built at Chandpal Ghat on the bank of the Hoogli, and the unfiltered river water was pumped and conveyed by means of conduits along the side of some of the metalled roads for road watering. Several large squares were laid out with tanks in the centre, many of the streets were lighted with oil lamps, and open drains were improved. In 1836 the lotteries were abolished owing to the force of public opinion in England. There are now over 270 miles of metalled streets and roads lighted with about 7,000 gas lamps and 2,300 oil lamps.

About 1856 the authorities appear to have awakened to a sense of their duties, and took steps to provide the City with a pure water supply and a proper system of underground drainage. The water had previously been obtained from the river opposite the City and from wells and tanks, the inhabitants storing the water in chattis and precipitating the suspended matter by the aid of alum. The foul drainage passed away in filthy open drains.

The Justices of the period were by Acts passed in 1856 required to carry out complete systems of pure water supply and drainage, and were empowered to levy rates and borrow money for such works. Schemes for both works were prepared and approved with little delay. The water supply was obtained by pumping from the river at Pulta 20 miles above Calcutta, where the water was free from salt and possible pollution from the sewage of the City.

The supply commenced in 1870 at 6,000,000 gallons per day, equivalent to 15 gallons per head of the population, which appears to have been about 400,000 at that time. The water was pumped from the river into settling ponds, filtered, and brought by gravitation through a 42" cast iron main, 12 miles, to a reservoir in the City, from which it was distributed through branch cast iron pipes along the principal streets. Cast iron pipes were also laid for the distribution of unfiltered water from the City Pumping Station (since dismantled) at Chandpal Ghat. The filtered and unfiltered water supplies have been gradually extended to the conditions which obtain at the present day, the former now amounting to 20,500,000 gallons per day to a population of 960,000 which includes the supply to small areas outside the Municipality, the latter 15,500,000 gallons per day to a population of about 740,000 persons.

The geological formation of the site of Calcutta for a depth of 25 to 30 feet is loam, sandy clay, and clay; a peat bed of about 18 inches can be struck at varying depths of 20 to 30 feet below the surface. A boring has been made to a depth of nearly 500 feet, but no rock was met with; sand and pebbles were struck at about 200, 300 and 400 feet, and peat beds at 30 and 300 feet below the surface. The absence of marine fossils shows that the strata denote deposits of fresh water, while the peat beds would indicate former land surfaces.

The surface is practically flat inclining from West to East with a slope of about 1 in 1,000. The area at present within the jurisdiction of the Municipality extends roughly north and south about 7 miles. The area of the City including the canal fringe is 4,237 acres; and that of the City, Fort William, Maidan, and added areas 13,237 acres. The population in 1901 of the City including the Canal fringe was 588,000 and that of the City and added areas 848,000.

The original sewerage project for the City proper was designed by Mr. Clarke in 1857; it was commenced in 1859. Brick egg-shaped sewers were built under the main streets, stoneware pipe sewers in lanes and alleys. By 1875, 35 miles of brick and 37 miles of pipe sewers were constructed. The sewers gravitated to a Pumping Station at Palmer's Bridge, where the sewage was lifted about 10 feet to a high level sewer by which it was conveyed about 8,000 feet to the "Salt Lakes" (swamps to the east of Calcutta). The greater part of the storm water was discharged by storm reliefs into the Circular Canal. The Local Government subsequently objected to the storm water being any longer discharged into this canal, and in 1882 the Municipality was compelled to construct an intercepting sewer for the purpose of collecting the storm-water, and discharging it to an open cut at Palmer's Bridge. This open cut conveyed the storm water from the main outfall and intercepting sewers to the Makalpotta Reflux gates, through which it passed to the Bhidiadhurry river.

By 1884 the old project and drainage of the City proper was practically completed, and had cost 95 lakhs of rupees.

In 1888 the area of Calcutta was augmented considerably by the addition of the Fringe, and Suburban, generally known as the Added, Areas. It then became necessary to prepare drainage projects for dealing with these extensions, and altering the City outfalls to meet future requirements.

Projects were formulated by the Municipal Engineers, and Mr. Baldwin Latham was asked to give his advice. He visited Calcutta and, "inter alia," pointed out serious defects in the old city system of sewers in cases where the branches join the mains "invert to invert," with the result that the free sewage flow from the branches in such cases is retarded and silt deposit takes place, which has

to be removed by hand at considerable expense. His recommendation with regard to the alignments and sizes of sewers for the new project was not adopted, although his advice generally was greatly appreciated. The counsel of the Municipal Engineers prevailed with the Corporation and the works estimated to cost about 68 lakhs of rupees were placed in the hands of the Contractors in 1897.

Through certain informalities, the works were suspended under the orders of the Government in 1900. Fresh plans of the scheme were prepared and submitted to Mr. Latham again for his report in 1901. His report had the effect of causing a large part of the project not already executed to be considerably modified, and the scheme in its modified form is now rapidly approaching completion.

The Calcutta drainage system (old and new) of the present day, as completed or being carried out, is roughly represented on the accompanying plan, Plate No. 67, and briefly described in the following notes. Only the main collecting sewers of the City area are shewn and are indicated by black lines.

The whole of the City sewers gravitate to the Pumping Station at Palmer's Bridge. This Pumping Station has been practically reconstructed under the new project and two out of the three old horizontal centrifugal pumps of the original station have been replaced by five Compound Vertical Inverted Jet Condensing Centrifugal Engines of about 100 L.H.P. The pumps with 136 revolutions per minute are each capable of lifting 2,100 cubic feet per minute through a height (lift and force) of 15 feet through the Town High Level Sewer. They shew an efficiency of 63 per cent. The suctions have no foot valves, the pumps are charged by steam ejectors in the pump casings; there are no valves in the pumps except a sluice valve on the delivery worked by a hydraulic pump. During the period these pumps have been in use, i.e., about 2 years, this installation, which

was supplied by Messrs. James Simpson & Co., has proved to be most suitable for pumping sewage.

Three of the pumps are capable of dealing with the maximum sewage flow of about 5,880 c.ft. m. at present being directed to this station, taken at 10 c. ft. per min. per 1,000 of the population of the area to be drained, 4,237 acres. The balance of power will deal with flush water and future increase. The summits of the main sewers are carried to the banks of the Hooghli where penstocks are fixed for the purpose of periodical flushing, *i.e.*, two or three days in every fortnight, when the height of the tides admits of this being done.

There are silt pits at Palmer's Bridge with wrought iron bar screens, 1½ spaces, to intercept matters that are inadvisable to pass to the sumps. The sewers are said to be capable of taking ¼ inch of rainfall per hour from the area drained and consequently discharge on the combined system. When the storm-water overcomes the capacity of the pumps or rises to a level above which the outfall sewers are likely to become surcharged, penstocks at Palmer's Bridge are opened, and the storm-water flows to a Storm Water Head Cut and Reservoir, recently excavated through the Salt Lakes, 4½ miles long and 100 to 700 feet wide, having a capacity of 52 million cubic feet, and capable of storing ¼-inch of rainfall per hour from the City area throughout the duration of the most inconvenient interval between tides in the Bhidiadhurry River, which was found by tide gauges to be 8¼ hours. At the two outlets of the reservoirs, sluices, fitted with Stoney's Roller Gates, have been erected to prevent the influx of river water, and admit of the contents of the reservior being discharged through 4½ hours of the ebb-tide; the Makalpotta Sluice, which has replaced the old reflux gates, has three gates, 14 feet wide and 17 feet high, and the Byntolla Sluice 5 gates, 15 feet wide and 19 feet high. The depth of water to which the

above quantity is estimated to rise over the sills of the Byntolla Sluice on the inside is 11 feet 6 inches. The river water on the outside rises to 17 feet above the sill.

A new high level sewer, 8 feet in diameter, capable of discharging 15,000 cubic feet per minute, has been constructed from Palmer's Bridge to what is known as Point A, where, with the discharge of the suburban system, the City sewage will flow along an open V-shaped concreted channel to the Suburban Storm-water Reservoir, finally discharging into the Bhidiadhurry river through the Suburban storm-water Reservoir and Sluice. Reflux gates are erected at the head of this Reservoir to prevent the sewage backing towards the City.

The Suburban Sewerage System now being carried out at a cost of some 45 lakhs, out of the budgeted 68 lakhs of rupees, and the new outfall works are shewn in red in the accompanying plan. The Main Sewer No. 1, draining 2,516 acres, is capable at its outfall of discharging 8,900 cubic feet equivalent to a maximum average sewage flow of 1,258 cubic feet per minute or 10 cubic feet per minute per 1,000 of the estimated future population of 125,800 taken as fifty per acre (the last census return for the area 33, plus 50 per cent increase), with a velocity of 2¼ to 2½ feet per second and also 7,642 cubic feet per minute or say 3 cubic feet per minute of rainfall per acre of the area drained. The sewers of the higher district will gravitate to the Budge Budge Road Steam Power Pumping Station, where both sewage and rainfall together will be lifted 13 feet by two centrifugal and two direct acting horizontal plunger pumps of a total of 54 P. H. P. The discharge will pass along a high level surface sewer to the Tolly's Nullah tidal channel, under which it is proposed to syphon it through two 30-inch diameter steel tubes laid through the bed of the nullah. The sewer then continues eastward to deliver the above quantities to the silt pits at Ballygunge Pumping Station.

Main Sewer No. 2, which near its outfall also takes the discharge of main sewers 4 and 5, was modified after 1901, and provides for the discharge of 10 cubic feet per minute per 1,000 of the future estimated population, plus twice that quantity of rainfall, or one-third sewage and two-thirds rainfall, from an area of 1,406 acres. The velocity of the maximum future sewage flow is estimated to range between $2\frac{1}{4}$ to $2\frac{1}{2}$ feet per second in the main sewers and between $2\frac{1}{2}$ to 3 feet per second in the branch sewers. When the sewers flow full, the velocity will be increased about 11 per cent. The future population is taken at the last census rate for the district drained, of 60 per acre plus 50 per cent. increase, or 90 per acre and the rainfall is estimated at $\frac{3}{4}$ of an inch per day over 1,406 acres. The full bore capacity of the sewer is estimated at 1,265 cubic feet per minute of sewage, plus 2,540 rainfall, or 3,805 cubic feet per minute, which will discharge into the silt pits at Ballygunge Pumping Station. The branch sewers of both mains range between 24 inches to 6 inches in diameter, and at the summits (generally 9-inch, 8-inch or 6-inch sewers) is a Miller's Automatic Flushing Chamber.

The Ballygunge Pumping Station will be provided with four Tangye's Coupled Compound Surface Condensing Centrifugal Side Suction Pumping Engines, each capable of raising through a height of 18 feet, 1,760 cubic feet per minute, or through a height of 10 feet 6 inches, 3,200 cubic feet per minute ; the plant has been so arranged that the maximum sewage discharge from main sewers 1 and 2 can be raised 18 feet to a high level sewer; or that the full discharge of these sewers in times of rainfall can be pumped through a lower lift of 10 feet 6 inches direct into the Suburban Storm-water Head Cut, by which it will flow to the storm-water reservoir and be discharged through the Suburban Sluice Gates to the Bhidiadhurry river.

The high level sewer will deliver the sewage at Point A, where with the City sewage it will continue in the combined

sewage channel to the Suburban Storm-water Reservoir and pass out into the river through the Suburban Byntolla Sluice, which is a sluice of 3 bays fitted with Stoney's Roller Gates of a similar design to those of the Byntolla Town Sluice.

The sewers, as will be seen from the above, take only a small proportion of rainfall. It is proposed to make provision for the disposal of storm-water from the suburbs by means of surface drains to discharge into the Suburban Head Cut.

For temporarily dealing with the undeveloped and poorer areas, Pail Depots, Public Latrines, and Bathing Platforms connected with the sewers are provided at various points of the City and Suburbs. Night-soil is collected from these areas and conveyed in buckets or carts to the Pail Depots. Other properties have either modern fittings or various types of Eastern sanitary fittings and are connected direct with the sewers.

Water from the streets in which sewers exist is carried off through gullies of the usual type.

The Author is much indebted to Mr. J. Ball Hill, A.M.Inst.C.E., for the above account.

CHAPTER X.

SEWERAGE OF KARACHI.

KARACHI is the capital, chief port, and military headquarters of Sind, and is situated some 500 miles to the north of Bombay City. The population, according to the Census of 1901, was 116,663, the Mahomedans largely outnumbering those of any other race.

Karachi has a Municipality with an annual income of 12 lakhs of rupees.

The water-supply is derived from wells which tap the subterranean beds of the River Lyari, about 18 miles from Karachi. From this source about 2,000,000 gallons of water a day are derived. The native city is drained on Shone's Hydro-Pneumatic Ejector System, which was designed and completed in September, 1905, by Mr. James Strachan, C.I.E., then Engineer to the Municipality.

Plate 68 shews the position of the existing ejectors and sewers in full black lines and the proposed extension of the sewerage system (referred to later on) in dotted lines. The area at present sewered is about 175 acres and contains, according to the Census of 1901, a population of 27,128. The cost of the work amounted to Rs. 5,97,000, which is equivalent to Rs. 21-10-3 per head of population.

The subsoil of Karachi is of a sandy nature, largely impregnated with brackish water, for which reason all the ejectors are placed in chambers of cast iron tubbing. This tubbing is made of cast iron flanged plates, 1¼ inches thick, built up in sections. Access is obtained to the ejectors from the road by means of a circular cast iron shaft,

in which a wrought iron ladder is fixed. The joints of all the tubbing plates were carefully planed and fitted together before being finally erected, to ensure their being water-tight. Strips of sheet lead were laid between the plates, which were then screwed tight, the joints being finally caulked. This arrangement has proved satisfactory and the ejector chambers are perfectly water-tight. The ejector stations are six in number and the ejectors are fixed in pairs in each station, each being capable of discharging 200 gallons. These, as well as the tubbing, were supplied by Messrs. Hughes and Lancaster of England, whose work has stood the test of time satisfactorily. The sealed sewage and air mains were provided and laid by the same firm. The air mains were tested to maintain a pressure of 55lbs. per square inch during a period of two hours. The gravitating sewers, owing to the nature of the sub-soil, were laid partly with cast-iron pipes and partly with glazed stoneware pipes ; the former being used wherever excessive water was met with in the excavation. The gradients for the pipe sewers vary from 1 in 80 to 1 in 150. The usual manholes and flush-tank arrangements have been provided, all manholes over 7 feet in depth being circular in shape and built of cement concrete rings, with the exception of five joining the ejectors, which are of cement brick-work.

Plate 69 shews the details of a concrete manhole as constructed in Karachi. The construction is well suited to a saturated sandy soil. The cement concrete was composed of 15 parts of broken stone, 10 parts of clean river sand, and 3½ parts of Portland cement. These manholes, which the Author inspected in April 1905, and which had been built nearly ten years, shewed no signs of wear and seemed in excellent condition.

At the head of each line of gravitating sewer, there is a flush tank fitted with an automatic siphon and connected by a service pipe to the nearest water main. The flush

tanks are of various capacities from 200 gallons downwards.

The sewers are ventilated on Shone and Ault's System of utilizing the exhaust air of the ejectors, which is discharged up a shaft, also connected with the sewer. This system is fully described in the earlier part of this book.

The air-compressing machinery was supplied by Messrs. Hughes and Lancaster and comprises two engines of about 25 Indicated Horse-Power, each capable of compressing sufficient air to deliver 375 gallons of sewage per minute from the six ejectors. The lift, including friction, does not exceed 130 ft., and the actual working lift, exclusive of friction, does not exceed 51 feet. The two boilers are of the type known as "dryback" tubular boilers. Each boiler is capable of supplying sufficient steam at 120 lbs. per square inch pressure to work one of the air compressing engines.

Plate 70 shews a Night-soil Depot in use at Karachi. It consists of a paved space, 50 feet square, on the centre of which the night-soil carts discharge their contents. This paved space slopes to two open chambers, in which are fixed gratings to intercept rags and stones. Each chamber is connected by a 5-inch pipe to a 6-inch pipe drain, connected in its turn with a pipe sewer. There is not much to be said for the arrangement from a sanitary point of view, as the night-soil is spread over a large area instead of discharging directly into the chambers provided for that purpose. The night-soil depots in use in Bombay, of which a plan is given earlier in this book, are much more sanitary than those at Karachi.

The whole sewage of Karachi is disposed of on a sewage farm, the location of which is shewn on Plate 68. The sewage is pumped through a 12-inch sealed sewage main to a raised masonry tank at the farm, through which

it passes by gravitation to the different plots. About 500,000 gallons of sewage are discharged daily on to the 70 acres of ground at present under cultivation. The sewage is used in its crude state, and, though purely domestic, is strong and arrives at the farm in a highly putrescent condition. The soil of the farm is light and sandy, and to this must be attributed the fact that any success whatever has attended the use of crude sewage. During the year ending 31st March, 1905, the profits derived from the farm amounted to Rs. 2,029, which is extremely satisfactory; for on no other farm known to the Author has crude sewage been used continuously for a decade with any success. Most of the ordinary fodder crops are grown, such as Makai or Indian corn, Jowari, red and white, Lucerne, Hariali grass, Guinea grass, Sugar-cane, and various kinds of English vegetables. Wheat has also been grown, but with no conspicuous success. Groundnuts and cotton give great promise. It is doubtful whether, even with such a fine soil as exists on this farm, the discharge of sewage without biological treatment can be indefinitely continued.

A large number of houses in the native city are now connected to the main sewers. These connections are simple in kind and consist of 4-inch stoneware pipes on which a running siphon is fixed just outside the premises. The 4-inch house connection pipe is connected with the sewer by means of an ordinary junction pipe.

Several public latrines of a simple kind and on the water carriage system exist in parts of the City, and when seen by the Author were working satisfactorily.

In October, 1901, Mr. J. Forrest Brunton, M.Inst.C.E., who succeeded Mr. J. Strachan, C.I.E., on his retirement as Chief Officer and Municipal Engineer, called the attention of the Corporation to the fact that for some time the drainage system had been giving a good deal of trouble

and that there was a constant overflow of sewage from manholes, etc. The cause of this, as pointed out by Mr. Brunton, was that the sealed sewage mains were of too small a diameter, and that therefore the engines and ejectors were not used to their full capacity. In consequence of the trouble, Mr. Brunton made a series of experiments on the efficiency of the Shone System, and he has recorded in his report, dated October, 1901, that the average efficiency of the system at that time was 0·182, this being the average of three trials. He also reports that the efficiency of the engines and compressors worked out to 0·850. This latter result is undoubtedly good. Mr. Brunton also works out very carefully the theoretical efficiency of the system at 0·340. The difference between that and 0·182, viz., 0·158, is due in his opinion to avoidable waste.

Mr. Brunton further states that the losses inevitable to this system of drainage are (1) loss due to the friction of the mechanism of engines and compressor; (2) loss due to the unnecessary heating of air during compression; (3) loss due to clearance in the compressor; (4) loss due to leakage in the air mains; (5) loss due to leakage at ejectors; (6) loss due to the impossibility of working air expansively in the ejectors.

Mr. Brunton concludes this interesting report by stating that the practical results were (1) that too much coal was being burnt, and that this might be remedied by substituting a Cornish or Lancashire boiler for the present type, and (2) that much more air was being used than the sewage discharge warranted.

In the spring of 1902, the Corporation decided to depute Mr. Brunton to Bombay to see the Shone System at work in that City and confer with the Author regarding the extension of the Karachi drainage. This proposed extension of the drainage, which has now been sanctioned by

Government, is shown on Plate 68 in dotted lines. An allowance of 20 gallons of sewage per day per head of population has been taken as a basis of calculation.

For the extension of the drainage, Mr. Brunton makes four proposals, the estimates for which vary from Rs. 9,75,000 to Rs. 13,25,000. Of these four, he recommends No. 3, the estimate for which amounts to Rs. 11,20,000. The ejectors and sealed sewage mains required for this scheme are shown on Plate 68. Briefly, it provides for ejector stations, each containing two ejectors of 200 gallons capacity, except in one instance, where the ejectors are to be of 1,200 gallons each, together with sealed sewage and air mains, gravitating sewers, night-soil depots, and engines and boilers with the necessary buildings. The extension scheme having been sanctioned, a loan is to be raised for a part of the work, which will shortly be commenced.

In the spring of 1904, Mr. Brunton wrote a paper entitled "Notes on the working of the Shone System of Sewerage at Karachi" for the Institution of Civil Engineers. This paper deals with some recent experiments made to ascertain the efficiency of the system. The average efficiency, based on 5 observations, was ascertained to be 0·336, but the actual working efficiency was only 0·263. This result is rather better than that obtained at Colaba in Bombay some few years ago, where the average efficiency was shown to be 0·225.

The Author is much indebted to Dr. S. M. Kaka, D.Ph., the Health Officer and Acting Chief Officer, and to Mr. Beaumont, the Chairman of the Committee of the Karachi Municipality, for their courtesy in placing all information regarding the drainage at his disposal, and for their kind attention during his visit to Karachi in 1905.

CHAPTER XI.

SEWERAGE OF RANGOON.

RANGOON is remarkable for being the first city in the East to establish the Shone Hydro-Pneumatic Ejector System of Sewerage. It is the capital of Burma and has a population of 240,000. The water-supply is derived from the Hlwaga Water Scheme, and is equal to 40 gallons per head of population per diem.

The works for the sewerage of Rangoon, on the Shone Hydro-Pneumatic System, were commenced in February, 1888, and were wholly completed during that and the following year. The first portion of the new system commenced working on the 10th August, 1889, and consisted of the drainage of certain blocks or districts. Other blocks were added from time to time.

The Shone System of drainage was, after considerable enquiry, applied as being the best suited to Rangoon's requirements. Previous to 1874, no attempt was made to deal with the excreta of the population, cess-pools were everywhere allowed, and the well-water, then the only water available, became fearfully polluted as the soil of the City became more and more honeycombed with cess-pools. Cholera and small-pox became practically endemic. In 1873-74 the authorities were forced to close the cess-pools in the town. Houses were provided with latrines, from which scavengers removed the filth during the night, conveying it in carts to jetties above and below the town, where it was thrown into the river at all states of the tide.

This primitive system had been condemned for years, and a Committee was appointed in 1881 to make proposals for draining the City. They decided upon a system of gravitating sewers; but no detailed estimate of the cost of the scheme was ever drawn up, and neither surveys nor borings were undertaken, for it was felt that a gravitating system of drainage for a perfectly flat, tide-locked city like Rangoon, could not under any circumstances be recommended on sanitary grounds, while the nature of the subsoil seemed likely to militate against its construction. Moreover, the combined system was deemed impossible in Rangoon with its heavy rainfall. The Municipal Committee deputed Mr. Clark, who was in England in 1884, to examine drainage works, to report upon the system most suitable for Rangoon, in consultation with those who had made a special study of drainage problems. Mr. Clark recommended the Shone System, which had proved highly successful in many places; and the Committee asked for a detailed project and estimate for the drainage of Rangoon on this system. The project was drawn up by Messrs. Shone and Ault, C.E., of Westminster, and Mr. Clark, and the Committee decided to adopt it, subject to the orders of the Local Government. The Local Government thereupon appointed a very strong Committee to investigate and report upon the project, and as this Committee's report was entirely favourable, the Government of India sanctioned a loan of 23 lakhs of rupees for carrying out the work.

The estimate of the cost of the work amounted to £188,633, and the Committee appointed by the Chief Commissioner reported that this estimate could be reduced to £174,721 by eliminating a portion of the proposed work, which sum at an exchange of 1/6½ would equal to Rs. 22,67,000. The loan sanctioned amounted to 23 lakhs of rupees, but it was found necessary to borrow another 7

lakhs to complete the scheme, as the work cost £174,695, and the average rate of exchange, at which the Committee had to pay, was $1/4\frac{15}{32}$ instead of $1/6\frac{1}{2}$, and also because the loan of 23 lakhs was taken at Rs. 91-10-8 per cent., so that only Rs. 21,08,333 were received for it.

Plate 71 shews the sewage mains, air mains, gravitating sewers, ejector stations, night-soil depots and flush tanks; and the following brief remarks will help to explain the Hydro-Pneumatic System as applied to Rangoon.

Rangoon had previously possessed a system of removal of some portion of its sewage, the excreta only, which if not absolutely dangerous, was a fertile source of nuisance. Moreover, it allowed sullage and all filth, not actually deposited in latrines, to saturate the soil, trickle into road-side drains and to ferment and load the air with abominable stenches. The Committee realized that, to remove sewage effectively and in accordance with sanitary laws, the drains would require a gradient greater than could be obtained in Rangoon. They therefore adopted the Shone System, as it obviates this difficulty, and allows of all drains being laid at such an inclination that sewage is rapidly removed, before it can become a nuisance or danger to health.

The portion of Rangoon drained on the Shone System is divided into 22 blocks ; and between every two lines of houses there is a space of 15 feet left for drainage purposes. In these spaces, 6-inch gravitating sewers have been laid at steep inclinations, none being flatter than 1 in 200. Each block is provided with Shone's automatic ejectors, into which the sewage flows by gravitation. The ejectors, which are in duplicate, each being of 200 gallons capacity, are fixed in iron tubbings at levels below the ground to suit the levels of the blocks from which they receive the sewage; and these ejectors, when full, automatically discharge the sewage into the mains. The sewage is

ejected into the mains from the ejectors by compressed air, which is supplied from the air-compressing station to small cast-iron pipes, which are connected with the ejectors by automatic valves.

The sewage mains are cast-iron pipes, varying in size from 6 inches at the extreme west of the town to 21 inches from the east of the town to the outfall near the Arracan Company's Mill, the sewage being ejected into the river below low water mark at a spot, where the set of the current is against the bank at all stages of the tide. By this arrangement, the sewage is immediately dissipated and does not accumulate.

At the end of each drainage space is an automatic flushing tank ; and in the centre of each of these spaces a night-soil depot was at first fixed. The flush tanks, which are of 200 gallons capacity, are placed at the head of each gravitating sewer and can be regulated to discharge as often as necessary. The night-soil depots were the necessary evils, until the houses were connected with the sewers. They are now done away with.

The air for working the sewage and water ejectors is compressed at a station in the eastern portion of the town and is laid on to the ejectors through pipes varying in size from 2½ inches to 10 inches. The air is compressed by means of triple-expansion, non-condensing engines, working with steam pressure of 150 lbs. per square inch above atmosphere. There are now five sets of engines ; but no more than three work together. Each set of engines has three air-compressing cylinders and the compressed air is stored in two air receivers, each being eight feet in diameter and twenty-four feet long. The cost of working the engines has been considerably reduced since they started.

The drainage plant at the Compressor Station consists of—

- Five complete sets of steam engines and air compressors, each able to work up to 90 indicated horse-power.
- Five Lancashire Steam Boilers, each of 75 nominal horse-power.
- Two Green's Economisers.
- Two Atkinson's Feed Water Heaters.
- Four Donkey Feed Pumps.
- Two Compressed Air Receivers.

The length of the mains and sewers is as follows:—

SEWAGE MAINS—

21-inch	3,582 yards
18 „	814 „
16 „	201 „
14 „	791 „
12 „	438 „
9 „	808¼ „
8 „	218½ „
7 „	4,492⅔ „
6 „	3,104⅓ „

Gravitating Sewers—

6-inch	38,510 yards, or nearly 22 miles of gravitating sewers.

AIR MAINS FOR SEWAGE EJECTORS—

10-inch	140½ yards
7 „	313 „
5 „	1,747 „
4 „	1,560 „
3 „	4,453 „

In September 1905, Mr. Edwin Ault, C.E., of the firm of Messrs. Shone and Ault, visited Rangoon, at the request of the Municipality, for the purpose of examining the sewerage system of the City as detailed in the earlier part of

this chapter and of advising upon improvements. By the end of October of the same year Mr. Ault reported that the present problem regarding the quantity of sewage to be expected from the area of Rangoon Town proper, was far more complicated than when the original project for the sewerage of the town was submitted in 1885 and carried out in 1887-1890. He gives the following figures of population at the Census of 1901 as being likely to aid one to realize the factors of the present problem:—

District.	No. of occupied houses.	Population.	No. of persons per house.
URBAN—			
Lammadaw	2,120	13,742	6·5
Tarkotan	2,487	17,004	6·8
N.-W. Town	3,280	18,089	5·5
S.-W. "	1,699	9,834	5·8
N.-E. "	1,423	7,857	5·5
S.-E. "	1,934	13,090	6·8
Koongyan	1,311	7,916	6·0
Total ...	14,254	87,532	6·14
Urban—			
Yegyaw...	1,863	11,411	6·1
Botataung	3,016	14,817	4·9
Total . .	4,879	26,228	5·4
TOTAL URBAN ...	19,133	113,760	5·94

District.	No. of occupied houses.	Population.	No. of persons per house.
SUBURBAN—			
N. Kemmendine	2,817	15,052	5·3
S. „ . . .	3,953	21,945	5·6
Theinbyu	5,751	26,173	4·6
Tamway . . .	3,142	23,119	7·4
TOTAL SUBURBAN ...	15,663	86,289	5·51
TOTAL SUBURBAN AND URBAN.	34,796	200,049	5·75
Rangoon Port . . .	1,303	10,641	8·3
„ Cantonment . .	1,435	13,721	9·5
Total ...	2,738	24,362	8·89
Rangoon City, North of River	37,534	224,411	5·98
Dallah	1,674	10,470	6·3
TOTAL RANGOON CITY..	39,208	234,881	5·99

The first totals refer to the region called "West Rangoon," which comprises the area to which the original sewerage project applied, and shews a population in 1901 more than double that anticipated by the Municipal Engineer in 1885. The second totals refer to "East Rangoon" or the part of the town which extends eastwards from Judah Ezekiel Street. The other figures are added principally to shew the same final figures as appear in the Census table.

Referring to the West Rangoon figures, it will be observed that the "N.-E. Town" has a population of 7,857 at the Census of 1901. This area comprises Block E 2 and E 3, and the figures give a density of 198 persons per

acre including the area of the streets. As there were constant overflows at the manholes on the sewers serving Block E 3, Mr. Ault paid particular attention to this area, and the Municipal Secretary arranged to enumerate the population residing there on the 8th October. His enumeration showed 6,241 persons. This gives a density of 315 persons per acre or an increase in $3\frac{1}{2}$ years of 59·1 per cent. on the density of N.-E. Town. Mr. Ault states that no portion of London of equal area possesses so great a density of population. The growth is remarkable, and has not yet reached the full limit ; for, to quote the Secretary's words, "There is likely to be a considerable increase in the population shortly in Block E 3, as several large tenement houses are in course of construction. As you are aware of course, there is a very considerable growth of population throughout the City area, probably not so great as in E 3, but still sufficiently apparent to make it necessary to form liberal ideas of what will be required from the sewerage works in the near future."

On examining the working of No. 17 Ejector Station (the one which is connected with Block E 3), Mr. Ault formed the opinion that a far larger quantity per head of sewage was flowing thereto than was ever contemplated in the original project or than was contemplated by the Hlawaga Water Scheme; and, besides having the population counted, he several times investigated the rate at which the ejectors were discharging. On the 5th October he found that from 7-12 to 7-57 a.m. there were 68 discharges. This is equal to an hourly rate of $90\frac{2}{3}$ discharges or $90\frac{2}{3} \times 200 \div 60 = 302$ gallons per minute. On one occasion the discharges at this Station were especially counted by picked men for 24 hours, the records shewing the number of discharges in every fifteen minutes. There were in all 1,061 discharges representing 212,200

gallons. The maximum occurred from 8-0 to 8-12 A.M. when there were 22 discharges, while between 8 A.M. and 9 A.M. there were 78 discharges. Sewage was overflowing at the street manholes during maximum flow, and there were also overflows from many sullage trays, owing to the grids being obstructed by solids and also to the sewers being surcharged, so that the 212,200 gallons does not represent the total water-supply during 24 hours. It should certainly be increased by 20 per cent. From the information so obtained the following figures are supplied:—

Water supplied . . .	$\frac{212,200}{6,241}$	=	34	gals. per head per day.
Add	20%		6·8	
Gross water supply . .			40·8	do.
Maximum rate of flow of sewage during 15 minutes	$\frac{22 \times 200}{15}$	=	293	gallons per minute.
Add	20%		59	
Gross maximum flow . .			352	do.
Maximum rate of flow of sewage during one hour	$\frac{78 \times 200}{60}$	=	260	gallons per minute.
Add	20%		52	
Gross maximum flow . .			312	do.

Minimum rate of flow of sewage during one hour	$\frac{30 \times 200}{60}$	=	100	gallons per minute.
Add	20%		20	
Gross minimum flow . .			120	do.
Mean rate of flow of sewage during 24 hours	$\frac{1,061 \times 200}{1,440}$	=	147·4	gallons per minute.
Add	20%		29·5	
			176·9	do.
Ratio of 15 minutes maximum flow to mean flow	$\frac{352}{176 \cdot 9}$	=	2:1 nearly.	
Ratio of 1 hour maximum flow to mean flow	$\frac{312}{176 \cdot 9}$	=	1·8:1 nearly.	
Population which would give the volume of sewage recorded, assuming 25 gallons per head per day . . .	$\frac{212,200 + 20\%}{25}$	=	10,186	

The records, so far as regards the discharges of the ejectors throughout the town taken hourly for one week, were too doubtful to enable one to deduce any sound basis for guidance as to the work required to be done at each

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station. This may be accounted for in several ways, *e.g.*, temporary blockages self-removed, more serious blockages removed by rodding, the personnel of the enumerating staff. The counting was entrusted to coolies from whom the tallies were collected hourly; and, judging from the erratic curves on the diagrams made from the records, it must be assumed that the human element has interfered to such an extent as to make these particular records of no value. The hourly revolutions of the engines, taken from the mechanical counters attached thereto, are far more reliable. They are embodied in the following figures:—

Total revolutions during the week .	1,549,574	
Mean hourly revolutions during the week	9,224	
Maximum revolution in any one hour (this was subsequent to heavy rain)	13,084	1:1·42
Minimum revolutions in any one hour	5,606	1:0·61
Mean maximum hourly revolutions during the week . . .	11,352	1:1·23
Mean minimum hourly revolutions during the week	7,102	1:0·77

The 13,084 revolutions were recorded for the hour 8 to 9 P.M., on the 21st September last and the mean revolutions for that hour during the week were 11,352, so that the excess of work due to rain was apparently $13{,}084—11{,}352 \div 11{,}352 \times 100 =$ about $15\frac{1}{4}$ per cent. It appears that rain water falling on 10 per cent. of the houses in the town finds its way into the sewers to a greater or lesser extent. This was never contemplated in the original project, nor has it been so since as evidenced by the Municipal Bye-Laws. The effect of allowing such rain water into the sewerage system is seen in the increased work of

the engines. As set forth before, it would be considered a sanitary arrangement to take into the sewers the washings and rain water falling on small cemented courts, with proper safeguards in the shape of fixed grids and traps to hold back silt; but this is a very different matter to taking roof water and water from unpaved and non-waterproof surfaces.

From the records of No. 17 ejector station it is clear that one must estimate the maximum rate of sewage flow to be dealt with by the ejectors at double the mean flow for the day. The engine records prove that the general system must be capable of dealing with a maximum flow of 1½ times the mean flow. The population figures corroborate the belief that the town will increase very rapidly and the number of residents will have doubled at the Census of 1911. As regards the volume of sewage to be reckoned per head per day, it cannot be supposed that it is 41 gallons all over the town, as it is in Block E 3, otherwise the other ejector stations would have been overpowered. At the same time there is no doubt that, when the Hlwaga Water Scheme comes into full operation, the use of water will increase with the more plentiful supply, so that one should reckon not less than 30 gallons per head per day, and, to be on the safe side, 40 gallons per day in view of the admission of water from cemented courts.

The town proper comprises the equivalent of 40 full sized blocks, omitting the Railway land and the Dufferin Garden. Allowing an ultimate average population of 6,000 per block, we get a total of 240,000 persons, which at 40 gallons per head gives a daily volume of 9,600,000 gallons of sewage, and 9,600,000÷1,440=6,667 gallons of mean flow per minute. The maximum flow to the outfall will be 6,667 by 1·5=10,000 gallons per minute. Allowing 3 feet velocity per second, this would require a pipe of 42-inch

diameter. The area of the present 21-inch main being deducted, it would leave an area equivalent to, say, a 36 main, as the requisite under the given conditions.

The average flow of sewage per block of 6,000 persons at 40 gallons per head per day equals 240,000 gallons per day or a mean flow of 167 gallons per minute and a maximum flow of 333 gallons per minute. There being six drainage spaces to a block, the average maximum flow from each would be about 55 gallons per minute. The 6-inch sewers are ample for the drainage spaces, but the collecting sewers along the cross drainage spaces and to the street manhole adjoining the ejector station ought to be of 9-inch diameter. Such pipes should be laid in all new blocks and the present 6-inch collecting sewers be gradually replaced by 9-inch pipes, commencing with the more urgent cases. The discharge pipes from the ejector stations should be gradually changed at existing stations as urgency demands.

In concluding his lengthy report, Mr. Ault makes the following proposals in their order of urgency:—

All open sullage channels to be replaced by pipe drains and no more open sullage channels permitted to be laid.

All private manholes to be built up to ground level and covered with stone slabs and iron manhole covers or to be replaced by iron pipes and inspection eyes.

All sullage trays in future to be of an improved pattern and defective ones replaced.

The cleaning of all sullage trays to be undertaken by the Conservancy Department.

Inspection eyes to be made larger, stronger, and of a form most convenient for rodding. Inspection

eyes to be surrounded by brick chambers covered with stone slabs or iron covers.

Foundations of brickwork or concrete to be built to support sullage trays, inspection eyes, soil and sullage pipes, etc.

Relay sewers in certain places. Urgent as regards several blocks.

Lay a new sewage main along Fraser Street, etc., and lay branch sewage mains from existing ejector stations thereto, as described.

Relay part of existing 18 and 21-inch mains.

Fit all ejectors with alternating valves.

Provide spare parts to ejectors.

Replace crank-shafts on Nos. 4 and 5 air compressors with new ones of stronger design.

Improve the foundations of Nos. 4 and 5 engines to prevent movement of beds.

Complete condenser plant to Nos. 4 and 5 engines and clear canal for water supply.

Put down a new air compressor.

Cover all steam heated surfaces at Compressor Station more effectually and provide spare parts to engines.

Lay 10 and 7-inch air mains as regards West of Judah Ezekiel Street.

Enlarge air branches to ejectors from 2 to 2½ inches diameter.

Improve drainage spaces.

Put down additional ejector station in Block E. 3.

In a further report, dated 8th December, 1904, Mr. Ault summarises the cost of his proposals and divides them

as to their urgency, so as to form a programme for proceeding with the work:—

A.—Works which are urgent and can be commenced immediately—

Item (*a*)—Laying down pipe drains in place of open sullage channels . . . Rs. 20.698

Item (*b*)—Building up private manholes or substituting pipes and inspecting eyes . „ 60,000

Rs. 80,698

B.—Works which are urgent and for which the material should be ordered—

Item (*g*)—Relaying certain pipe sewers with larger pipes. The most urgent blocks requiring these are given in para. 11 (13 blocks) Rs. 1,49,500

Item (*h*)—New sewerage main and branches —

Municipal . Rs. 4,55,529

T.L.R.D. . „ 10.256

Rs. 4,65,785

Item (*k*)—Alternating valves to ejectors . .

Item (*s*)—Enlarging air branches to ejectors . . .

„ 15,600

Carried over...Rs. 7,11,583

	Brought forward...Rs.	7,11,583
Item (*m*)—Replacing crank-shafts	„	7,500
Item (*p*)—New air compressor . . .	„	1,04,313
Item (*r*)—New air mains, Municipal . .	„	57,989
Para. 30—Venturi Meters measuring sewage	„	13,000
	Rs.	8,94,385

Of the above the following are either works on private property, or are renewals, *i.e.*, not strictly capital expenditure or are on T. L. R. works:—

	Rs.
Works on private property items (*a*) and (*b*)	80,698
Renewals, item (*m*)	7,500
T. L. R. works, part of item (*h*) . .	10,256
Rs.	98,454

This would leave a balance of urgent work, being Municipal Capital expenditure of (Rs. 8,94,385—Rs. 98,454) =Rs. 7,95,931.

C.—Works which are urgent but for which prices are not immediately available, and which should be undertaken as soon as prices are obtained:—

Item (*c*)—Purchase of 319 sullage trays ;

Item (*l*)—Purchase of spare parts to ejectors ;

Item (*q*)—Purchase of covering to steam heated surfaces and provision of spare parts to engines.

Para. 31.—Copper steam and feed piping and steam traps.

All these items should come under the head of renewals and not of capital expenditure.

D.—Works which are not urgent but which should be carried out as the extension of the sewerage system, the making of house connections, or the improving of the Compressor Station demands:—

Item (*f*)—Foundations to house connection fittings.		
Item (*g*)—Relaying sewers with larger pipes.		
Item (*h*)—Prospective sewage mains—		
Municipal . . .	Rs. 56,254	
T.L.R.W. . .	„ 46,521	Rs. 1,02,775
Item (*i*)—Relaying 18 and 21-inch sewage mains.		
Item (*n*)—Improving foundations of Nos. 4 and 5 engines.		
Item (*p*)—New compressor to deal with the whole expected sewage as soon as old engines can be removed .		Rs. 1,60,000
Item (*r*)—Prospective air mains—		
Municipal . .	Rs. 26,466	
T.L.R.W. . .	„ 49,260	Rs. 75,726

As a large portion of item (r), especially on the Reclamation works, will be required very shortly, it is advised that the whole of item (r), both "urgent" and "prospective," be undertaken at the same time while the special gang and staff are on work, as the work on the jointing of air mains is more special than that on sewage or water mains and, when the workmen have been trained to their work, it would be wiser that they should be kept on for the whole of the air mains.

The Author is much indebted to Mr. Edwin Ault, C.E., for the information contained in the above account.

CHAPTER XII.

SEWERAGE OF SINGAPORE.

SINGAPORE is the principal commercial centre in the Straits Settlement and has a separate Colonial Government. It consists of an island, 27 miles long by about 14 miles broad, lying at the south end of the Malay Peninsula. Situated within 1° of the Equator, it possesses a very temperate climate, the annual range of temperature being between 70° and 90° Fahrenheit. The annual rainfall measures about 92 inches. Singapore has largely increased in size of late years, and now boasts of a population of 150,000.

It has no regular system of sewers. The whole of the sullage from baths and kitchens is conveyed by open road-side drains, constructed along the sides of the streets, which ultimately discharge into the tidal river and the sea at various convenient points. These drains are cleansed and swept twice a day by Municipal coolies.

The City is for the most part flat, and the lower portions are occasionally submerged by extraordinarily high spring tides.

There are a number of public latrines on the dry system in various parts of the City, and the contents of the pails and pans are frequently conveyed to cocoanut plantations beyond Municipal limits. All excreta from houses is similarly removed daily by Chinese coolies to vegetable gardens outside Municipal limits.

In 1893, the late Mr. MacRitchie, M.Inst.C.E., submitted to the Municipal Commissioners a scheme for the

removal and disposal of all excreta. In this report he pointed out how dangerous the existing system was and how completely the City lay at the mercy of a set of men, who might at any moment strike work. He also pointed out that a complete system of sewerage for the City would, on account of the natural configuration of the City and the suburbs and the soft nature of the soil, be attended with very great cost, both in the construction of the sewers and the maintenance of powerful pumping engines, necessary to raise the sewage to a sufficient level to discharge it by gravitation into the sea. Mr. MacRitchie's proposals were to collect the excreta and convert the same into poudrette, he being of opinion that the material would command a ready sale among planters and others. In 1897 the Municipal Commissioners decided to instal a small plant at Tanjong Pagar Reclamation, which was completed and started in 1898. Since that date the installation has been at work, but it has always worked at a loss, and if extended to the whole of the excreta of the City, would occasion a daily loss of 1,000 dollars to the Municipality.

Early in 1904, the present Municipal Engineer, Mr. R. Peirce, M.Inst.C.E., submitted a report to the Municipal Commissioners in which he laid down that the discharge of night-soil into the sea was the most satisfactory way of dealing with the problem before them. He further decided that the main channel on the south side of St. John's Island would be the most suitable position for that discharge, the currents at this place being east and west. Taking 1½ lbs. of night-soil and urine per head per day, he estimated that 100 tons per diem would have to be removed.

His scheme for the disposal of the night-soil was to divide the City into districts and to have in each district a Shone's ejector, which would receive the excreta and then discharge it into a sealed sewage main, varying in

size from 3 inches to 8 inches at the final landing jetty, whence it would be discharged into barges and from them be shot into the sea. Plate 72 shows the positions of the proposed five ejector stations, the route of the sealed sewage main being indicated by dotted lines. It is proposed that all the latrines in the City shall be furnished with pails of one pattern supplied and maintained by the Municipal Commissioners. These pails are to be 12 inches deep by 1 foot 3 inches in diameter and covered with a lid, which is made air-tight by a rubber joint secured to the pail by a spring. Each of the five districts would contain 3,000 houses and the pails would be removed once in 2 days. This would mean the removal of 1,500 pails to each receiving ejector every day. The pails would be removed in vans and clean pails would take the place of those removed from latrines. The estimated quantity of excreta to be dealt with at each receiving ejector would be 4,050 gallons or 18 tons. The total cost of the proposed scheme, exclusive of the cost of pails, is estimated at 580,710 dollars and the annual working expenses at 239,008 dollars.

It is not proposed to make any alteration at present in the existing road-side open drain system for the disposal of sullage.

The Author is much indebted to Mr. R. Peirce, the Municipal Engineer of Singapore, for his courtesy in supplying the information contained in this note.

CHAPTER XIII.

SEWERAGE OF GEORGE TOWN, PENANG.

George Town is situated on the island of Penang just off the West Coast of the Malay Peninsula in North Latitude 5 degrees 24 mins.

The town is situated on a Cape, as its Malay name of Tandjong implies, and is roughly triangular in shape, two sides being bounded by the sea and one side by the mountains which rise to a height of about 2,700 feet.

The population of the town is about 100,000 persons, more than half of which are of various Chinese races. There is also a large proportion of Indian people and a smaller number of the original Malays. In addition to these there are representatives of practically every race in Asia and Polynesia as well as Europeans. It will thus be seen that the ideas and prejudices of a very dissimilar people must be regarded in this town.

The average amount of rainfall is about 112 inches and is of the usual tropical nature with heavy thunderstorms and rains, the effect of which is perhaps accentuated by the close proximity of the mountains. Rainfalls at the rate of 1 inch per hour are fairly frequent and an even faster rate is not unusual.

The town is built on a flat alluvial plain with a very slight fall from the foot of the hills to the sea, a great part of the town being not more than two or three feet above high water level spring tides. The rise and fall

of spring tides is about 10 feet, but during neap tides the water level remains practically stationary for several days at about half tide level.

In former years, a large amount of flooding took place and the lower stories of European, Chinese, and Indian dwellings were often flooded for days together. The Malay houses being built upon piles did not suffer in this way.

The inconvenience caused by flooding need not be enlarged upon, and it was decided to take steps to improve matters. In the closely built upon areas it was considered advisable to take means to stop flooding of the houses entirely, while in the Suburban districts it was considered sufficient if floods could be carried off within the 24 hours.

The flooding in town was also accentuated by the fact that a number of main roads, more or less in embankment or with large side ditches, radiated from the town to the suburbs, and the general fall being from the country towards the town, the main drainage of these areas followed the roads and so largely increased the amount of flood water to be dealt with in the lower districts.

As a first step to check flooding, intercepting channels were constructed across the general line of drainage above referred to, and so arranged as to intercept the flood water flowing from the suburbs towards the town and lead it by shorter routes to the sea. In forming these channels, advantage is taken of a number of cross roads constructed in embankment to form one side of the channel and divert the flood water. These channels are constructed partly in concrete and brickwork and partly as earth channels. In the suburban districts it was not considered advisable to incur the expense of constructing channels large enough to entirely prevent flooding. The channels in these districts are therefore constructed of a size large enough to deal with about 1/3 inch of rainfall per hour. The result

has been fairly satisfactory and a great improvement upon former years. A small amount of flooding however still occurs as might be expected.

In the closely built upon areas it was considered advisable that all flooding of dwellings should cease and the main drains are made large enough to discharge 1 inch of rainfall per hour. This figure is found to be about sufficient for heavy rainstorms. No doubt the rain often falls at a faster rate, but a certain amount is absorbed by the ground or otherwise retarded in its flow, and the rate of flow off any area does not appear to exceed this figure. Owing to the fact that the general level of the town is only a few feet above sea level it is obvious that the drainage system could not be made self-cleansing unless a pumping system were adopted.

The cost of a pumping system to deal with sudden and heavy floods of the nature already described would be very heavy. No attempt has therefore been made to construct a self-cleansing system of sewers and the drains are of the open pattern and regularly swept out and flushed down by coolies employed for the purpose. No fœcal matter is admitted to the drains and the water-supply is ample. No nuisance is caused by the sweeping out of the drains, and no difficulty is found in obtaining low-caste Indian coolies willing to do this work. The system has proved satisfactory in this climate and gets over the difficulties, due to sewer gas and the blocking of traps by unsuitable substances thrown into the drains by half civilized people.

All closets are built outside the houses and are provided with pails, and the night-soil pails are removed by vans in the early morning.

Household refuse is removed by scavenging carts and excluded as far as possible from the drains.

The drainage system is therefore only called upon to remove the waste water from houses, rainfall, &c., and is not of a very foul character.

The drainage channels are constructed by enlarging the roadside drains and lining them with impervious materials, formed to a suitable cross section and properly graded.

Brick channels have been found by most Engineers to be difficult of maintenance in good condition with smooth surface, as the mortar in the joints is liable to become disintegrated, and the bricks themselves have generally a rather rough surface.

A much smoother surface can be obtained by cement plaster over concrete or brickwork, but the cement is liable to become damaged, and with drains in constant use, the repair of a cement invert is very difficult and a good job is seldom made.

The system of drainage, as adopted in Penang, is to construct the invert of half round tile pipes, bedded on concrete, and the sidewalls of concrete plastered with cement and coped with bull nose blue bricks.

The ordinary drainage is carried by the tile invert, while in time of flood the whole channel may be nearly filled.

This system has been found satisfactory, as the tile invert forms a smooth surface, requiring very little sweeping, and being practically self-cleansing.

A typical channel cross section with a general plan of the town drainage is shown on plate 73.

The Author is much indebted for all the above to Mr. L. M. Bell, M.Inst.C.E., Municipal Engineer of George Town, Penang.

The system of drainage, as adopted in Penang, is applicable to small Municipalities with a limited water-supply, and whose finances cannot stand the strain of an expensive underground system. Such a system, as Penang has, cannot be considered to be ideal, as it can only dispose of waste water and not of fæcal matters. The application of a channel pipe open drain has been found advantageous in Bombay for the same reasons, as those given by Mr. Bell, and was first introduced many years ago into Bombay by the Author.

CHAPTER XIV.

SEWERAGE OF SHANGHAI.

SHANGHAI, situated in Lat. 31·11 N., Long. 121·25, is by far the most important ot all the Treaty Ports of China. It may be divided into three areas:—

(i) The Native City (*i.e.*, within the City wall) which has an area of square mile and a population of 110,000.

(ii) The French Settlement (adjoining the Native City) which has an area of about half a square mile.

(iii) The International or Foreign Settlement which has an area of $8\frac{3}{4}$ square miles and a population of over 450,000 Chinese and 11,000 Europeans, excluding the shipping population.

The present article deals only with the International or Foreign Settlement, but the description may be considered as applicable also to the French Settlement, although the Native City, in regard to drainage and other Municipal matters, occupies no better position than that of an ordinary Chinese town of several centuries ago.

Shanghai is situated on the River Whangpoo, 14 miles above its junction with the Yangtszekiang. The normal rise and fall of the tide is about 11 feet. The water is fresh and highly charged with suspended matter, mostly of an alluvial nature.

The country both in the Settlement and for miles around is very flat, the substratum consisting of an

alluvial deposit. The general ground level of the Settlement is only about 2 feet above H.W.M.O.S.T., and the undeveloped portions and the surrounding country are intersected by numerous tidal creeks, which are utilized as far as possible as sewer outfalls.

The rainfall in Shanghai averages 43·60 inches per annum, the variations of which are shown in the following table:—

SICCAWEI OBSERVATORY.

INCHES OF RAINFALL.

1873—1902.

	Max.	Min.	Mean.	Mean Temperature F.
January	7·77	0·03	2·15	37·4
February . . .	4·25	**0·00**	2·29	39·2
March	6·00	0·59	3·21	46·2
April . . .	9·43	0·92	3·57	56·5
May	7·17	1·11	3·60	65·5
June . . .	**19·37**	0·74	**6·66**	73·4
July	11·63	0·12	5·10	**80·6**
August . . .	13·52	0·49	5·94	80·2
September	10·79	0·78	4·72	72·7
October . . .	11·79	0·31	3·31	63·3
November	5·93	0·10	1·85	52·0
December . . .	**3·64**	**0·14**	**1·13**	**42·1**
Inches	62·53	27·92	43·60	59·2
				Range 43·2

June is pre-eminently the rainy month, both for frequency and abundance. In June, 1875, there was a rainfall of 19·27 inches in twenty-one days.

The devotion of the Chinese to agricultural pursuits forms the solution of the economical disposal of the ordure of the Settlement, and the Municipal Council derives a net income of Tls. 47,770 (£7,000·1906) therefrom, a

native contractor paying that sum for the right of collecting night-soil in the Settlement. This contractor provides all labour and covered receptacles for the collection, and is under bond to convey it in boats to rural districts without causing nuisance in the Settlement. The system works well and the whole of the night-soil is removed daily before 9 A.M. Water closets are prohibited under the local bye-laws, but urinals and slop-water sinks are connected with the sewers. Owing to the numerous outlets provided by the natural creeks there are no large main outfall sewers, the largest being 3′-0″ × 2′-0″. Tidal flap valves are not used and the tide is left free to circulate through the sewers, whose inclination (owing to the flatness of the district) rarely exceeds 1 in 500. Wherever possible, dead ends are avoided, in order that the tidal water may circulate through the various systems.

The majority of the roads (of which there are 87 miles) are macadamised, and consequently a large amount of detritus finds its way to the street gullies, which are also emptied periodically.

Complaints as to emanations from the gullies are practically non-existent.

Rigid supervision is maintained over all private drainage works, and no drains are allowed to be covered until they have been inspected and approved by the Council's Inspectors.

Owing to the difficulty of obtaining stoneware pipes at a reasonable cost, the Council in 1891 decided to manufacture its own pipes of concrete, and these pipes are used for all Municipal work, and also supplied to private individuals. Within the last three or four years, all pipes up to 12″ diameter have been made by machine, and compare favourably for porosity and durability with glazed stoneware pipes. They are made of the usual pattern in 2-feet

lengths with spigot and socket joints. Other pipes of the following standard sizes are also manufactured:—

Circular, 2′ and 3′ diameter.

Oval, 2′-3″ × 1′-6″ and 3′ × 2′.

These are all reinforced by iron rods. Street gullies of the usual pot form are also made.

Wherever new roads are made through country districts, where the rateable value does not justify the laying of a sewer, the drainage is effected by means of a ditch, 10 feet wide on the top and 6 feet deep, cut on one side of the road. When such districts get built up, these ditches are filled in and sewers laid in the ordinary manner.

The water-supply of the Settlement is in the hands of the Shanghai Waterworks Company, Limited, and the supply is drawn from the Whangpoo River, about two miles below the town. The water is drawn off at high tide and goes through a process of settling tanks and sand filters. The quality of the water is excellent, as may be seen from the following analysis by the Health Officer:—

Sample received, 25th November 1905.

Report sent out, 30th November 1905.

Sample.—Shanghai Waterworks Co.'s water.

Physical Characters.—Pale yellowish green colour with slight opacity.

	Parts per 10,000
Solid matters in Solution	15·0
(*a*) Volatile	7·0
(*b*) Fixed	8·0
Appearance on ignition, slight charring.	
Total hardness	11·0
(*a*) Temporary	5·0
(*b*) Permanent	6·0
Chlorine	2·7
Nitrogen as Nitrates	0·03
Saline Ammonia	0·02
Albuminoid Ammonia	0·015
Poisonous Metals	*Nil.*
Nitrates	*Nil.*
Phosphates	*Nil.*
Sulphates	**Traces.**

Bacteriological Examination.—Nutrient gelatine plates incubated at 23° C shewed 200 micro-organisms per cubic centimetre. The ratio of liquefying to non-liquefying organisms was one to ten.

Agar plates incubated at blood heat yielded 40 microbes per cubic centimetre.

Report on Analysis.—A sample of well filtered water shewing a high degree of chemical and bacteriological purity.

The Author is indebted for the above interesting notes to Mr. Charles Mayne, M.I.C.E., the Engineer and Surveyor to the Shanghai Municipal Council.

CHAPTER XV.

SEWERAGE OF BENARES, LUCKNOW, AND MIRZAPUR.

In February, 1906, the Author visited the Sewerage Works of Benares, Lucknow, and Mirzapur in company with Mr. Lane Brown, M.Inst.C.E., M.I.M.E., the Supervising Engineer.

All these works were then in progress, those at Lucknow and Mirzapur possessing peculiar interest, in that an open sewerage system is being applied to both cities. The short description given below will suffice to shew how well-suited this system is to Eastern cities or towns having only a small water supply. When an urban water supply does not exceed 10 to 12 gallons per head of population, sewerage as adopted at Lucknow and Mirzapur is undoubtedly the best. The Author was much impressed with it, as well as with the excellence of the work carried out by Mr. Lane Brown, by whom the works are carried out departmentally, subject to the scrutiny and approval of the Sanitary Engineer to Government, Mr. D. W. Aikman. The economy thus secured, as against contract agency, is very considerable, and the Government has been so favourably impressed with it that they have agreed to a similar procedure for Fyzabad, Allahabad, and Muttra, as also for many of the small Municipalities of the United Provinces. These works are now either in project or progress.

Benares.—Benares is the holiest city of the Hindoos, and is situated on the Northern bank of the Ganges, with

a population of 208,000, of whom nearly 60,000 represent a floating population of pilgrims. The water supply is 4½ million gallons per diem and the rainfall averages just over 40 inches per annum.

The first complete scheme for the sewerage of this city was designed in 1889 by Mr. A. J. Hughes, M.Inst.C.E., the then Supervising Engineer for Municipal Water Works. North-West Provinces and Oudh. The scheme was on the combined system, that is to say, stormwater and sewage were both to be removed in the same sewer. Mr. Hughes' scheme provided very good gradients for the sewers and also two pumping stations, through which it was proposed to lift the sewage twice. The main outfall for the whole system was to be constructed at a site on the river Ganges, half a mile below the city, and the discharge was to be into 40 feet of water when the river was at its lowest in the hot season. The cost was estimated at Rs. 19,12,218 and the working expenses at Rs. 36,760 per annum.

At the end of 1890, Mr. Baldwin Latham, the eminent Sanitary Engineer, was invited to India to advise the Municipalities of Bombay and Calcutta regarding their drainage problems, and advantage was taken of his presence to obtain his advice on the proposed scheme for the sewerage of Benares. The report which he submitted in February, 1890, shewed that provision should be made for a population of not less than 300,000 people. He approved generally of Mr. Hughes' scheme, but recommended that no pumping should be undertaken and that the scheme should be based entirely upon gravitation. This necessitated a certain reduction of the velocities which Mr. Hughes had contemplated and provided a velocity of three feet per second with sewers running half full. Mr. Latham took the ordinary dry weather flow at 4 c.ft. per head per day, which gave roughly a mean flow of 700 c.ft. per minute. He agreed with Mr. Hughes that though it

was generally desirable to exclude the rainfall from sewers, in this particular instance it was better to combine the rainfall with the sewage. In the present new project full provision has, however, been made for the exclusion of storm-water.

As to the disposal of sewage, he recommended its discharge direct into the Ganges, without any kind of treatment, and rightly pointed out that the great dilution which would immediately occur would destroy all germs of disease.

Mr. Baldwin Latham's recommendations reduced Mr. Hughes' estimate by Rs. 2,11,642.

In 1898, Mr. Lane Brown, who succeeded Mr. A. R. Wilson, M.Inst.C.E., as Resident Engineer, took charge of the work and has carried out the present scheme.

In 1899-1900, financial reasons obliged Government to revise Mr. Latham's scheme and to reduce the estimate to Rs. 14,00,000. The whole of this scheme has now been successfully carried to completion departmentally, and a project has been prepared for the completion of the remaining portions at a cost of Rs. 20,00,000. Construction will commence during the year.

Many of the sewers are laid at a great depth in lanes, which do not average more than six feet in width with overhanging houses of from four to six stories on each side. In spite of great difficulties, these sewers were most successfully laid. Benares, for very many years, possessed an old system of obsolete drains which had their outfalls at various points on the Ganges, and these always existed in the narrow lanes. It was necessary in constructing the new sewers to arrange for the carriage of the sewage in sheet iron troughs with lead joints whilst the old sewers were being demolished and removed, until the new sewers were complete. The greatest care had to be expended upon

this task, in view of the caste prejudices of the workmen engaged, and also in view of the probability of the collapse of houses which were built mostly on uncertain foundations. Be it remarked to the credit of the Engineer that the whole work was carried out without any damage or compensation of any sort.

Pending the erection of ventilating shafts, for which arrangements are, on account of local prejudice, being slowly made, ventilating manhole covers provide the only means of ventilation, which is effected at ground level.

Automatic flushing tanks are provided at the heads of all sewers.

Plate 74 is a drawing of a water-carriage system latrine, which has been introduced into the United Provinces by Mr. Lane Brown. Some thirty of these latrines have been erected and many have been in use for five or more years, having given great satisfaction. They provide fully for the wants of the poorer classes and are in popular favour. Some of the largest have 96 seats and are used by 4,000 people daily. The Author carefully examined some of these latrines and found them free from any nuisance. Attached to each latrine is a pail depot of simple and economical construction, which works well.

Benares is the only City in the Province which is, or is likely to be, sewered with the exception of Cawnpore. Most of the other towns are, or will eventually be, drained on the open system, as being, where practicable, the best suited to the needs and uses of the people.

The details of the Cawnpore sewerage system have been based on the experience gained in the Benares works.

Lucknow.—Lucknow is the capital City of the Province of Oudh, and is included in the United Provinces. It is situated on both banks of the River Gumti, which is a tributary of the Ganges.

It ranks fourth in size among Indian cities and has a population of nearly 300,000. The water-supply of the City is 2,000,000 gallons per day or about 10 gallons per head, and is derived partly from wells, but principally from the River Gumti, from which it is pumped and then filtered.

The sullage of the whole City is removed by means of open surface drains, which also carry off the surface water in the monsoon. The annual rainfall averages 40 inches and the surface drains are calculated to deal with a flow of 2 inches per hour per acre. Provision has been made for the sullage water to be wholly carried in a new system of open drains and free use has been made of certain old drains which are connected with *nálahs* discharging into the river for storm overflows. Many streets possessed these old drains which received the surface water and sullage through side lanes.

Covered drains have now been constructed in these lanes with which open surface drains have been connected, the lanes themselves being paved. In no instance do the surface drains run to any great depth.

For drainage-purposes, the City has been divided into seven districts, each with its outfall into the Gumti. To obviate the disadvantage of having open drains at a great depth, the streets have been raised or lowered according to requirements. When it has been necessary to lower a road, the houses have been underpinned.

Plate 75 gives the details of the cross-section of these open drains. They are all carefully calculated for the size of the district they have to serve. Though not shewn in the Plate, the invert is in all cases constructed of lime and cement concrete moulded at a central store, and the working face of the invert is of neat Portland Cement. The result is excellent and sanitary. No night-soil is admitted into the surface drains, but it is at present removed by hand

and trenched outside the City. Under the scheme, however, the Benares type latrines and pail depots will serve the whole city, each having its separate system of purification and the effluent only will be allowed to enter the surface drainage.

The total estimate for the sewerage of Lucknow is Rs. 20,00,000, of which Rs. 4,00,000 have been spent up to date. The Cantonments are not included in the above scheme.

At each of the seven outfalls, the surface drains will discharge into Liquefying Tanks, from which the effluent will pass on to a continuous filter provided with a Fiddian Distributor. So far only one full installation has been completed, and when the Author saw it, the Fiddian Distributor was doing excellent work. Figure No. 44 shews a similar distributor now working at Enfield, England. The Distributor has the great advantage of discharging the effluent in a thin wave on to the filter.

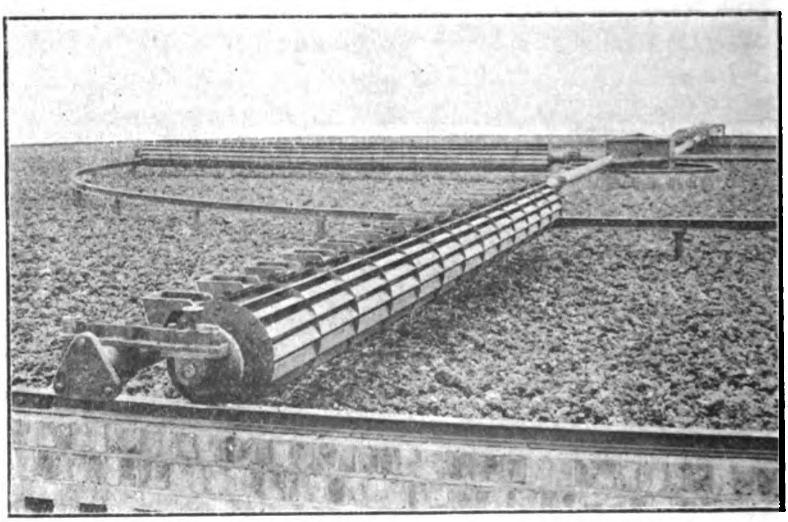

FIG. 44.

The above system of drainage is also well suited to smaller Indian Cities and, if well conserved, would appear to serve every sanitary requirement. In the smaller lateral drains, a *bhisti,* in conjunction with a sweeper, can deal with 3,000 feet of open drain, both morning and evening, and keep both the drains and paved lanes in a most satisfactory condition. For the larger laterals and mains, flushing tanks—both hand and automatic—are provided.

Mirzapur.—Mirzapur is situated on the south bank of the Ganges, some 60 miles below Allahabad. The population is 56,000 and the rainfall averages 40 inches per annum. The present water supply is derived from wells and the River Ganges, and is calculated to be equal to about 3 gallons per head per diem, but a new water supply project, on a basis of 12 gallons per head, and estimated to cost Rs. 5,00,000, is at present under consideration and will shortly be commenced.

The City lies for the most part on the banks of the river, and, as is often the case with riparian cities in India, the land falls back from the banks. The drainage has, therefore, to be carried out against the lie of the land, necessitating deep excavations in places where *nullahs* running down to the river do not exist.

From time immemorial, Mirzapur has contained old masonry drains, which, though large and well constructed, are of a somewhat obsolete shape.

The sewerage is being carried out on the same lines as those previously described in the case of Lucknow, and the design of open drains is as shewn in Plate 75. Streets have been raised or lowered according to the requirements of the gradients of the drains.

It has been found necessary to cover some of the open drains for short distance with stone slabs, with suitable manholes, since the configuration of the land necessitated their being laid at a great depth.

Five outfalls into the Ganges are proposed for the discharge of the sullage, and the purification will be on the same principles as at Lucknow.

At present, all excreta is removed by hand and trenched outside the town, none being admitted into the drains, but the scheme embodies the same provision of latrines, pail depots and separate purification as at Lucknow.

The sewerage works are now nearing completion and are estimated to cost Rs. 2,25,000.

CHAPTER XVI.

SEWERAGE OF ALEXANDRIA.

At the end of 1902, the Author, at the request of the Egyptian Government, was asked by the Municipality of Alexandria to give his opinion on a scheme for the sewerage of that City which had been recommended by the late Dr. J. Hobrecht, Chief Engineer to the City of Berlin, and designed by L. Dietrich Bey, Chief Engineer to the Municipality of Alexandria.

The population of Alexandria, taken at the Census in 1897, was returned at 319,760. Since that year it has increased and may be calculated at 400,000 at the present time. Alexandria has an excellent and never failing water supply, supplied by the Alexandria Water Company from the upper reaches of the Mahmoudieh Canal and filtered before delivery into the City mains.

In the year 1902, the Company supplied 25,500 metres or 5,610,000 gallons of water per diem, equivalent to 85 litres or 18·5 gallons per head of population.

The rainfall of Alexandria is very slight, and is mostly confined to December and January, the average annual fall for the last thirty years (1869 to 1899) being only 224·8 millimetres or 8·47 inches.

The configuration of Alexandria approximates to that of Bombay, that is to say, a considerable part of it is low-lying, being nearly at mean sea level. The range of the tide is so little around Alexandria that it can safely

be left out of consideration so far as the sewerage is concerned.

Some thirty years ago, the export merchants of the City founded an Association and voluntarily contributed to a tax for the paving of the streets of a part of the City known as Minet-el-Bassel. Subsequently, they extended their operations to other parts of the City and increased the scope of their work by constructing a series of drains for the removal of surface water, but these drains were never intended for sewage.

The City, so far as its sewerage was concerned, remained in this condition until the year 1885, when the Egyptian Government appointed a Commission to report *inter alia* on the sanitary condition of Alexandria. The Commission condemned the existing drains for the use of sewage, but nothing further was done. In 1895 Dr. J. Hobrecht, Chief Engineer to the City of Berlin, reported favourably on a scheme for the drainage of the City which had been proposed by L. Dietrich Bey, Chief Engineer to the Alexandria Municipality. This scheme was to dispose of all the sewage of the City by gravitation on a combined system and to discharge it in a crude state into the sea. It was proposed to construct a main sewer or collector, of ovoid shape, alongside the quay wall built between Pharos and Silsileh. This sewer was to receive sewage from nine smaller sewers and was to discharge into the sea at both its ends. This main and the smaller sewers were to be fed by a series of pipe sewers, serving the different districts of the City. Many of the gradients proposed were too flat to ensure satisfactory velocities.

There were many objections to such a scheme. The shape of the ovoid sewer was obsolete, and, where the rainfall of a City is so very small, that shape of sewer is not to be commended. The effect of discharging all the

sewage of the City into a collector, the outfalls of which are only partially submerged, is bound to be disastrous. Moreover, the discharge of a large quantity of crude sewage into the sea close to a City is a most objectionable proceeding and is certain to be fraught with serious results. The Author on these grounds reported against the scheme.

The configuration of Alexandria does not lend itself to a sewerage scheme entirely by gravitation.

Its close proximity to the sea provides a natural and economical outfall for sewage, but the latter must be biologically treated before being discharged.

APPENDICES.

APPENDIX I.

BACTERIAL SEWAGE PURIFICATION.

Hydrolytic Tank and Oxidising Beds

BY

W. OWEN TRAVIS, M.D., M.S., Barrister-at-Law,

AND

EDWIN AULT, C.E.

Conclusions and Propositions based upon Researches into the Purification of Sewage.

The conception of "The Hydrolytic Tank and Oxidising Beds" is the result of a close study of the numerous experiments conducted at Lawrence under the ægis of the State Board of Health of Massachusetts, and published by that Board in a series of works, which, in their entirety, constitute a classical record of the bacterial purification of sewage.

This being so, an acknowledgment of the source from whence the ideas were derived and a recital of the conclusions having special reference thereto are, as a matter of common honesty as well as of courtesy, equally desirable.

The conclusions come to by the officers of the State Board relating to

ANÆROBIC TREATMENT

briefly stated are as follows:—

(a) "The results obtained (in the septic tank) during 1899 (when, owing to the low rainfall, considerably stronger sewage had to be dealt with) have strongly indicated that the greater the amount of organic matter in the sewage entering a septic tank, the greater will be the percentage reduction of organic matter by the tank treatment." This observation suggests the idea that "where exceedingly large volumes of sewage are to be purified, as in the case of the sewage of a large City, this sewage could be passed through ordinary settling tanks, so constructed that the sludge settling to the bottom of these tanks could be flushed into a septic tank and this sludge alone be treated by septic tank action, instead of attempting to treat the whole of a City sewage. Following up this idea, a septic tank was put in operation during September, 1899, to receive the strong sludge from settled sewage." The results of this experiment, up to and including the year 1901, were "that the tank contained about 20 per cent. of the organic matter of the sewage which had entered it during its period of operation," and "as the effluent contained about 22 per cent. . . . . about 58 per cent. was liquefied or otherwise changed and given off as gas by the tank action during its period of operation." This was a rate of purification which exceeded that occurring in an ordinary septic tank during the same period, notwithstanding that in operating the tank the sewage was not moving through continuously, as the effluent passed from the tank only during the short time each day that concentrated sewage was being passed into it.

(b) "During the first winter of its operation, there was a constant accumulation of sediment within the tank," which was believed to be "due to the long period that the

sewage remained in the tank at that time and the consequent diminution of bacterial growth on account of the production of toxins." It is probable, however, that the absence of the pipe openings (*i e.*, absence of ventilation) upon the top of the tank, which were subsequently introduced, prevented the escape "of certain gases that, when held in solution in a closed tank, were inimical to the continuation of bacterial life."

(*c*) "The matter in suspension in sewage is the chief factor in clogging the surfaces of . . . filters. . . . By the action of the septic tank, a very large proportion of these matters in suspension is eliminated from the sewage when it flows from the tank. A certain proportion changes its form and goes into solution in the sewage, while another portion is changed to the gaseous form and escapes: while undoubtedly at times, as has been repeatedly noticed at Lawrence, considerable very finely divided solid matter comes from the tank. This occurs at times when the movement of the gas in the tank disturbs the sludge, and, while only lasting for a few minutes at a time, causes considerable solid matter to flow out in suspension."

(*d*) "It is evident, from our experiments, that the bacteria in the tank that do the larger proportion of the work live on the sides, bottom, and top of the tank, where organic matter accumulates and where they are found in enormous numbers compared with the numbers found in the liquid that is passing through the tank;" hence an experiment was inaugurated in 1899, "in which sewage was passed upwards through a tank filled with broken stone, in order to afford a very extensive foothold and breeding place for the necessary classes of bacteria. Comparing the average analysis of the effluent of this anærobic tank or filter with the average analysis of the effluent of the septic tank A, we see that the percentage reduction of organic matter was greater in the former, and that an effluent was produced

containing a smaller amount of matter in suspension and hence more easily filtered at high rates." In 1901, when the applied sewage passed through filter in about six hours or nearly four times as fast as similar sewage passed through the septic tank, it was found that "the principal obstacle in operating an anærobic filter such as this compared with the operation of a septic tank, is the greater difficulty in removing accumulated sludge, if we assume, as seems reasonable, that in both cases sludge will (when treating most sewages, eventually) accumulate to such an extent that its removal will be imperative."

These conclusions clearly indicate the following propositions:—

1. That as the liquid portion of water-carried sewage contains matter in solution only, and as the water has already fulfilled its principal function, *viz.*, the conveyance of the grosser particles, so it should be permitted to pass through the tank in the limited time necessary for purely sedimentary purposes.

2. That as the suspended matters of the sewage only require to be subjected to a prolonged digestive process, so these matters, together with the minimum amount of liquid which is found to be necessary for the free flowing of the particles and for the carrying away of the liquefied products, should alone undergo the septic tank or hydrolytic treatment.

3. That as, in any sedimentary tank, some of the matters in suspension, whose specific gravity differs little from the liquid, will not be deposited, and as in all septic tanks considerable quantities of deposited sludge, disturbed by the gases of decomposition, will constantly flow out of the tank with the liquid, so a further purification in an upward anærobic filter is absolutely necessary.

4. That as the gaseous and volatile products are, like the liquid products, equally subversive of micro-organismical hydrolysis as they are the cause of the strong odours which prevail in a septic tank effluent, and as they are detrimental to the subsequent oxidation in contact or other ærating beds, so they should be removed, by exhaustion, from the tank as they are formed.
5. That as sludge must accumulate, so means must be provided for its systematical withdrawal. Any attempt to establish a so-called equilibrium is futile; it is, in fact, but a method of evading the issue and of throwing upon the subsequent treatment matters which ought to be effectually dealt with in the tank.

NOTE.—The Hydrolytic Tank has been devised in conformity with, and in order to secure the advantages of, the foregoing propositions.

The conclusions of the Massachusetts State Board Officers relating to

ÆROBIC TREATMENT

may be stated as follows:—

(a) "All our studies have shewn that it is extremely able that the sewage, before passing to contact filters, should be treated by some method, such as settling, straining, or bacterial action in the so-called septic tank, that will remove from it as much as possible of the matters in suspension: and they have apparently proved that, if contact filters are to be kept in operation for a considerable number of years, they must receive sewage which has been clarified in some such way, or else the filter must be of such coarse and smooth material that all suspended matter will pass readily through it."

(b) "When sewage in an advanced state of putrefaction is applied to a contact filter, and the entire open space of the filter filled with this sewage, it is possible that oxidation may be so rapid that the supply of oxygen within the

filter will be exhausted before the process of nitrification has had time to begin, that is to say, even if the nitrifying bacteria are in the sewage when it is passed to the filter, or in the filter at the time of the introduction of the sewage, their power may be entirely overcome temporarily by a lack of oxygen. . . . . . It is evident that if sewage in the condition of septic sewage B upon the date of the first experiment flowed into a contact filter, filling it entirely, no nitrification could be expected to take place within the filter, as the oxygen with which it would come in contact would probably not be more than enough for the first rapid oxidation, this quick oxidation being probably a chemical action rather than the bacterial oxidation upon which nitrification depends. When such sewage . . . . . is run in a comparatively small volume upon the surface of intermittent sand filters, however, it remains upon the surface in most instances long enough for considerable oxidation to take place, and it meets a large volume of air as it slowly passes through the filter and hence nitrification occurs."

(c) "As, moreover, this rapid absorption of oxygen did cause a change in the character of the organic matter of the sewage that could be readily detected by the ordinary chemical analysis, experiments were undertaken to shew whether or not it was the oxidation or saturation of gases. . . . . These experiments were repeated and seem to prove conclusively that the rapid absorption of oxygen was by gases or by organic matter that, sterilizing by heat, had so changed that it was not easily oxidized, rather than by bacterial action. This makes clear one of the reasons for the difficulty of nitrifying certain septic sewage. Can we not, however, satisfactorily explain these results by assuming that we have groups of bacteria of different characters, producing ptomaines that seriously interfere with nitrification? We know that. . . . . . the condition obtaining in tanks must be quite different one from the other, and the

organic matter in the sewage must be worked over to a different extent or by different bacteria, giving different end products. . . . . . It is certain that if the anærobic process is carried too far, there may be a formation of distinctly poisonous bodies, which might prevent nitrification."

(*d*) "The effluents of properly constructed and operated contact filters contain very little organic matter in suspension. When the effluent flows from a filter, air is drawn into the filter again and fills the open space. Consequently, a partial oxidation of the organic matter left within the filtering material proceeds until this oxygen is exhausted, when the open space is completely filled with the chief products of this oxidation,—namely, carbonic acid, marsh gas, nitrogen of the air primarily present, and nitrogen liberated during decomposition,—and the filter will remain with its open space filled with these gases until they are removed by the introduction of sewage or air. This condition reached, the activity of the oxidizing and nitrifying bacteria within the filter ceases and anærobic action begins."

(*e*) "It seems probable that the organic matter, both that in solution and that in suspension, is worked over and digested by the bacteria in the filter, first by the anærobic and then by the ærobic bacteria. By this process the matter is, in the first place, rendered unsuitable food for the anærobic bacteria, and perhaps toxic to them. When in this condition, however, it is suitable food for ærobic bacteria, which rapidly at first and then more slowly change it to this stable condition."

(*f*) "These studies have proved quite conclusively that, while the intermittent continuous filter of coarse material is, perhaps, more difficult to operate on account of the necessity of uniform distribution of the sewage over the surface, etc., yet. . . . . they can be operated at higher rates than

contact filters, and will generally give better purification results: that is, nitrification within them is generally more active, the organic matter remaining in the effluents more thoroughly changed and the appearance of the effluents somewhat better. . . . . . The reason (for which) is undoubtedly the greater volume of air that comes into contact with the sewage as it passes through these filters the thinner streams of sewage. . . . . continually passing in thin layers over the filtering material, and are thus continually in contact with the bacteria upon the filtering material and also in contact with air; while in contact filters the main volume of sewage is, when the filter is standing full, not in contact with the material, but filling the voids between, and ærobic bacterial action is limited by the volume of air remaining in the filter after filling as much as possible of the open space of the filter with sewage."

(*g*) "Another interesting and practical point. . . . . . is that the matter in suspension. . . . . accumulates more slowly within the intermittent continuous filter; for when reaching a certain degree of change or bacterial oxidation, it is continually falling from the filtering material in flakes and appearing in the effluent. In the contact filter . . . . this tendency to loosen from the material is less marked, and hence these filters lose a greater percentage of their open space,—a serious matter in all filtration at high rates by means of coarse filters, but more especially so with contact filters," as the rate really "depends upon the open space."

(*h*) "A difference of a few degrees in the temperature of the sewage entering the bed causes a considerable difference in the degree of nitrification taking place within the filter in winter."

(*i*) "We have sometimes found the highest nitrification and the smallest number of bacteria when there was a large supply of the ammonias in the effluent. This would indi-

cate that the most complete destruction of bacteria was not due to a failure of food, so far as that may be supplied by the free albuminoid ammonia of these effluents, but was rather due to the process of the formation of nitrates,—the burning process. We have thought that their destruction might be due to being deprived of oxygen that was used in the oxidation of other organic matter; but it may be due to their own oxidation,—to their being burned."

These deductions substantiate the following propositions:—

1. That as a 'contact bed' must infallibly become inoperative when treating crude sewage, owing to the accumulation of sludge on its surface and in its interior, so some method of clarification must be resorted to in the first instance.

2. That as the purification effected in a 'contact bed' is dependent upon a cycle of anærobic and ærobic actions, so a good 'contact bed' must necessarily be an imperfect ærating bed.

3. That as the effluent from a septic tank contains organic matter in such a condition and gases of such a nature that the oxygen primarily present in the contact filters was exhausted by direct oxidation of carbonaceous matter before nitrification could become established, so a septic tank effluent should not be submitted to 'contact bed' treatment, but to some more perfect means of æration.

4. That as the purification results of an intermittent continuous filter are uniformly superior to those of a 'contact bed' in quantity as in quality, so the latter must go, and methods adopted in order to overcome the difficulties incidental to the working of the former.

5. That as the gases produced in the contact or other ærating bed, equally with those contained in a septic

tank effluent, interfere with the purification results, so provision must be made for the systematical exhaustion of those gases from the bed, as well as for the introduction into the bed of fresh air.

6. That as the nitrification results are adversely affected by cold weather, so means must be taken to prevent any great loss of the heat in the sewage, and, during the continuance of cold weather, the air introduced into the bed should be heated.

7. That as "the period of greatest destruction of the ordinary sewage bacteria corresponds closely with the time of most active nitrification and most complete æration," so the cultivation of the nitrifying organisms and the acquisition of the freest admission of air must constitute appropriate means for inhibiting the passage of living pathogenic germs.

NOTE.—The Oxidising Beds have been so designed as to be in compliance with the requirements of the above-mentioned propositions.

* * * * *

DESCRIPTION OF THE HYDROLYTIC TANK AND OXIDISING BEDS.

Plate 76 illustrates the Hydrolytic Tank, which is divided into two parts.

The first part consists of two "Sedimentary Chambers" laterally situated and a central "Liquefying Chamber."

The sewage having first passed through a "Detritus Tank," enters the Sedimentary Chambers and traversing their length emerges therefrom over the weirs *aa.* as indicated by the arrows. The time thus occupied (about five hours) suffices for the deposition of the suspended solids of the sewage. The deposited matters gravitate through openings *bb.* at the bottoms of the dividing walls of the

chambers, and are accompanied with, and accelerated by, a proportion of the liquid being allowed to flow into and through the Liquefying Chamber. The section of the latter chamber, below the level of the openings *bb.* provides for the reception and accumulation of the deposited sludge pending its hydrolysis; the section of the chamber above the openings *bb.* provides for the flow of the liquid and for the carrying away of the gaseous and liquid products, due to the hydrolysis of the deposited matters; the time occupied by the liquid in passing through the Liquefying Chamber being about fifteen hours. The relative flow of the liquid through the Sedimentary and Liquefying Chambers, both as regards velocity and quantity, is regulated by the relative capacities of the chambers and the widths of the respective weirs.

When the sludge has been sufficiently hydrolised, or when its level approaches that of the openings *bb.* the valves *cc.* are successively opened and the lowest portion of sludge that most digested, is forced through the sludge pipe *d.* by the head of the liquid in the tank.

The effluents from the Sedimentary and Liquefying Chambers, and such finely divided or light sedimentary matters as may be carried therewith, overflowing the weirs drop into and become intimately mixed in the channel *e.*

The second part of the Hydrolytic Tank, to which the liquid now passes, consists of a series of "Upward Anærobic Filters" filled with flint stones or other material of suitable size. The mixed effluent is deflected to the bottom of the first filter, as indicated by arrows, and passes upwards through the material (leaving the suspended matter adhering thereto) and overflowing the dividing weir is again deflected to the bottom of the second filter, passes through the material of the second (and third or more filters) and finally issues from the tank at *f.* occupying

during its progress through the second portion of the tank about three hours.

Should there be any accumulation of sludge in this part of the tank, provision is made for its withdrawal in a manner similar to that described in connection with the Liquefying Chamber.

The Hydrolytic Tank is, as a whole, covered in, and the gases and volatile products generated therein are continuously and systematically exhausted by means of a fan in order to keep the gas tension within the tank, and that of the contained liquid at as low a pressure as practicable, so as, on the one hand, to avoid the possibility of any explosion, and on the other to obviate some of the difficulties incidental to the objectionable odours and to the subsequont treatment of the effluent.

From the Hydrolytic Tank, the effluent is taken to "Oxidising Beds" (shewn in Plate 77) on to which the liquid is delivered intermittently by means of a syphon arrangement. The liquid is collected in syphon chambers of such a capacity that each is filled in not less than say ten minutes, and when full the contents are discharged automatically by means of the syphon *g.* on to the upper or Nitrosifying Layer of the beds and percolating there through, falls on to and through two or more Nitrifying Layers fixed underneath, the final effluent being drawn off by the Channel *h.*

The even distribution of the liquid on to the upper layer is secured by having the Syphon *g.* of such a discharging capacity as to deliver the liquid with a rapidity sufficient to flood a bed, the surface of the latter being protected from disturbance by perforated tiles, wire netting, or other device. The liquid capacity of the Nitrosifying

Layer should be about equal to that of one discharge from the Syphon Chamber, and the layer itself should be formed of coarse sand or other suitable material of such grade as to allow of one charge of liquid to completely percolate through before the next is ready.

The Nitrifying Layers should be formed of coarse gravel or other suitable material of such grade as to provide convenient space for the growth of the nitrifying organisms, so that the phagocytic action and the dependent organismal filtration may be developed to the fullest extent, and at the same time that provision be made for efficient æration.

The successive layers of the Oxidising Beds are separated from each other by spaces through which a current of air is drawn by a fan, and through which the liquid falls from one layer to the other, thus providing the necessary oxygen for the life work of the organisms and a means of conveying away the gases produced thereby.

By admitting the air to the beds through a pipe or conduit, the volume can be controlled and also the air can be heated in order that, during severe weather, the best conditions may be established for the maximum activity of the organism.

The author is indebted to Dr. W. Owen Travis and Mr. Edwin Ault for their permission to print the above.

Since the appearance of the pamphlet containing the foregoing interesting matter, Dr. W. Owen Travis has carried out a large number of systematic examinations on the action taking place in the various sections of the Hydrolytic Tank, which go to shew that besides the bacterial action so thoroughly examined by the Massachusetts Board of Health, there is an important physical process occurring,

which would account for the clogging up of "bacteria beds" probably to a greater extent than the passage of matters in suspension.

It had been observed that contact beds not only clogged at the surface but right through the whole depth of the beds, and it has been difficult to account for this clogging by the action only of suspended matter. Dr. Travis found that a clean effluent from the first part of the Hydrolytic Tank still deposited a much larger volume of solid matter in the second part of the tank than was represented by the solids in suspension passing thereto. He even found that if the effluent from the first part were filtered so that no solids were in suspension, the filtrate coming into contact with walls, plates, or stones, for example, continued to deposit solid matter. The latter were evidently in an unstable soluble form, in what has been designated a colloidal state or an emulsion, which, on being brought into contact with solid surfaces, have their physical unstable equilibrium disturbed and become separated into more stable solid and liquid forms. In contact beds the solids so separated have no doubt contributed largely to the clogging of their whole depth.

The result of these examinations has been the entire remodelling of the second part of the Hydrolytic Tanks. A series of thin plates, at a slight angle from the vertical, are placed at small distances from each other, for the double purpose of presenting a large contact surface for the effluent from the first part of the tank to impinge against, and to allow of the solid matters gravitating down to the floor of the beds. The flow of the liquid is from the bottom upwards, and a space is formed below the bottom edges of the plates for the accumulation of the sludge, when it is drawn in a manner similar to that in the first part of the tank.

The result of the entire operation is an effluent very greatly superior to any hitherto procured, as can be seen from the following table of comparative results:—

	Liquid capacity.	Solids in suspension remaining in the effluent.	Percentage reduction in albuminoid nitrogen.
1st—"Continuous undisturbed Sedimentation" Septic Tank—London County Council's Fourth Report, 1902	6 hours	50·5 %	Not stated
Hydrolytic Tank (1st portion)...	6 "	2·0 %	57·7
2nd—Septic Tank (Average results,	24 "	50·0 %	44·0
Hydrolytic Tank	12 "	1·0 %	64·8
3rd—Experimental Septic Tank—Massachusetts State Board of Health's Thirty-Fourth Annual Report, 1902 (2,000 gallons)	22 "	46·1 %	40·0
Model Hydrolytic Tank (300 gallons per day)	12 "	1·0 %	77·6

The sewage flowing over the weirs of the first portion enters the second portion of the tank. The latter consists of three hydrolising chambers, which are arranged in sequence. The sewage passes to the bottom of the first chamber by a descending channel, rises slowly in the chamber and flows over a weir, enters the descending channel of the second hydrolising chamber, rises upwards through that chamber, and repeats the operation in the third chamber.

Each chamber—with the exception of a clear space above for the flow of the liquid controlled by a submerged wall (built to keep back a small amount of floating matter) and a space below for the accumulation of sludge, from which it can be withdrawn—is occupied by thin plates separated by 4″ spaces, through which the liquid passes. Plates so arranged attract particles to them, which accumulate until their weight exceeds the power of attraction,

when they slip from the plates and fall into the sludge space below. This accumulation is, in the main, confined to the upper surface of the plates, and the gases, freely generated, escape and pass upwards along the under surface of the plates. The analogy between the first and second portions of the tank can now be seen. In the first or hydrolytic portion the gases generated in the sludge space are prevented from interfering with the settling solids by the walls of the liquefying chamber, and in the second portion or hydrolising chambers each plate separates the ascending gases on the under surface from the deposited solids on the upper surface. These experiments have indisputably shewn that the hydrolising chambers, when fitted with plates in the manner described, are immeasurably superior in working than chambers fitted with broken stone, etc., as hitherto used.

APPENDIX II.

SPECIFICATIONS.

Stoneware Pipes.—The pipes shall be stoneware made from clay devoid of lime and its compounds.

Each pipe with its socket shall be made in one operation and in one mould, and shall be of the best quality, perfectly straight, cylindrical, thoroughly salt-glazed and burnt, and free from cracks, flaws, and defects of every description.

The thickness of each pipe shall be at least one-twelfth of its diameter, and in every case in which the word "diameter" is used, it shall mean internal diameter. The depth of the socket of a pipe shall be not less than 12 inches.

The length of a pipe, wherever stated, is to be the length exclusive of the socket, that is to say, the length of effective work that may be done by the pipe.

The pipes shall be finished with a perfectly smooth interior, and shall, when struck with an iron rod, ring clearly.

A piece of about 2 inches square, broken from any part of the pipe, shall not absorb after 48 hours' immersion in water more than 2 per cent. of its weight of water.

The pipe shall be capable of resisting a bursting pressure of 30 lbs. per square inch and all the pipes found to be leaky or incapable of sustaining the pressure specified,

or to be more absorbent than hereinbefore stated, shall be rejected.

The breaking or crushing weight of a pipe shall be not less than 1,700 lbs. applied by means of a lever or otherwise to the centre of a board of hard wood laid along the top of the pipe throughout its length exclusive of the socket. The pipe, when subjected to this test, shall be supported on a similar board underneath, the socket overhanging clear. A layer of felt shall be laid between the pipe and the board both at the top and the bottom.

The test for absorption, bursting pressure, and breaking weight shall be applied to one pipe selected by the Engineer out of every twenty pipes offered for delivery. If the pipe so selected withstands an internal pressure of about 30 lbs. per square inch and a breaking weight of 1,700 lbs. applied as above described, and if a piece taken from it and tested for absorption as stated above, does not absorb more than 2 per cent. of its weight of water after 48 hours' immersion, the whole of the twenty pipes from which the one was selected as a sample may be taken over. If the pipe selected burst or break under the applied test or absorb more water than specified, then the whole of the twenty pipes shall be subjected to the various tests.

Portland Cement.—The whole of the Portland cement shall be of the best quality now manufactured in Great Britain by some well-known maker; it shall be securely packed in strong wooden casks and shall have arrived from Great Britain not more than two months before the same is tendered for delivery.

Each cask should be strongly bound with hoop-iron, should be lined with water-proof paper, and should bear the trade mark or the label of the manufacturer. The cost of the cask will be held to be included in the rate to be

paid for the cement. No damaged or leaky cask will be received.

Each cask shall weigh when delivered at least 385 lbs. gross and 375 lbs. net.

The specific gravity of the cement shall not be less than 3·05.

The whole of the cement shall pass through a sieve containing 1,600 holes per square inch; and 95 per cent. shall pass through a sieve having 2,500 holes per square inch, and 85 per cent. through a sieve containing 5,625 meshes to the square inch.

Test blocks shall be made with 20 per cent. of water, and the mixture shall be placed in the mould without hammering and kept one day in a moist atmosphere. 60 per cent. of the blocks shall be made of neat cement and 40 per cent. of cement and sand in the proportion of one part of cement to three parts of clean dry sand. The neat cement blocks shall be capable of maintaining without breaking a tensile strain of not less than 350, 450, and 580 lbs. per square inch after immersion in water for seven, fourteen, and twenty-eight days respectively. The cement and sand blocks shall bear a pressure of 125 lbs. after fourteen days and 200 lbs. after twenty-eight days.

Slabs or pats of cement made with 20 per cent. of water, kept in air until set and afterwards immersed in water for twenty-four hours, shall shew no signs of cracking or softness.

A sample of cement shall be made into a paste and put into a glass test tube. If the test tube is cracked or the cement shrinks away from the sides, it shall not be accepted.

Cast Iron Pipes.—The cast iron pipes shall be cast vertically in dry sand moulds with the socket ends

downwards and shall have a sufficient head (not less than nine inches) on the spigot end of each pipe, which head must be subsequently cut off in a lathe. They must be of uniform bore and thickness of metal throughout without belts. The metal shall be the best gray metal, re-melted from the cupola, and not run direct from the blast furnace, and to be perfectly free from scoria, air-bubbles, flaws, or defects of any kind. It must be tough, close-grained, and cast as hard as can be conveniently drilled or tapped, but shall nevertheless not present on being broken a white or vitreous surface of fracture.

The metal shall be of such strength, that a bar 2 inches in depth by 1 inch in width and 40 inches in length, weighing not more than 21 lbs. will, when supported at points 36 inches apart and loaded in the middle, sustain a weight of not less than 28 cwts. for twenty-four consecutive hours, and shall deflect not less than 0·3 of an inch before breaking. Six test bars, as described above, shall be cast from each and the same running as the pipes are cast from, and shall be tested in suitable and proper machinery.

All pipes, after being well cleansed and fettled, shall be carefully coated internally and externally by being immersed whilst hot in a hot bath of pitch and oil, according to Dr. Angus Smith's process: the coating shall be applied at a proper heat and in a proper manner before any rust has formed. The surface of the coating of the pitch shall be quite black and shall retain a smooth, glossy surface, and adhere firmly to the pipes all over, and be incapable of being mechanically separated from them.

Any pipe, which shall be unsound or in any way imperfect, or in which any sand holes shall be found plugged up, or which shall not admit of a circular disc 1-16th of an inch less than the diameter of the pipe passing freely through at right angles to its axis, shall be rejected.

All pipes shall be as near as possible of the weights set forth below, and no greater deviation than 3 per cent. either above or below these weights shall be permitted.

Internal Diameter.	Length exclusive of Socket.	Thickness.	Weight of each Pipe.	Depth of Socket.	Thickness of Lead joints.
Inches.	Feet.	Inches.	Cwt. qr. lb.	Inches.	Inches.
1½	6	9/32	0 1 7	2¾	1/4
2	6	5/16	0 1 21	3	
2½	6	5/16	0 2 7	3	
3	9	11/32	1 0 0	3½	3/8
4	9	3/8	1 1 21	3½	
5	9	27/64	2 0 0	4	
6	9	7/16	2 2 0	4	
7	9	15/32	3 0 18	4¼	
8	9	½	3 2 21	4¼	
9	9	33/64	4 1 14	4¼	
10	9	17/32	5 0 0	4¼	
11	9	9/16	5 3 1	4¼	
12	12	19/32	8 3 0	4½	
13	12	39/64	9 3 0	4½	
14	12	41/64	10 3 0	4½	
15	12	43/64	12 0 0	4½	
16	12	45/64	13 2 0	4½	
18	12	¾	16 1 0	4½	
20	12	13/16	19 2 0	4½	
21	12	53/64	20 3 0	4½	
24	12	⅞	25 0 0	4½	
27	12	15/16	30 0 0	4½	
30	12	15/16	33 0 0	5	
33	12	15/16	36 2 0	5	
36	12	15/16	40 0 0	5	
40	12	1 1/32	48 2 24	5	
42	12	1 1/32	51 0 7	5	
48	12	1 1/32	65 1 18	5	

The pipe shall sustain and withstand proof by hydrostatic pressure equal to 260 lbs. on a square inch, and while under this pressure the pipe shall be repeatedly and sufficiently struck in all its parts with a hammer of a weight suitably proportioned to the strength of the pipe under examination. During the time of making the examination the pipe shall be kept dry, so as to exhibit the more readily the effect of the pressure applied.

Shone's Ejectors and Tubbing.—The Contractors shall provide and deliver two pairs of Shone's Pneumatic Ejectors, each ejector being capable of discharging 150 gallons per minute. (The size of ejectors and the place of delivery may be varied according to the requirements in each case).

The ejectors shall be arranged in pairs, so that they can work alternately.

The receiver shall be of wrought-iron provided with an inspection door, and shall be tested at the contractors' works to a pressure of 100 lbs. to the square inch.

Each ejector shall have an inlet and outlet pipe of such size that the velocity of the sewage in the inlet pipe when carrying the contract rate of flow shall not exceed 180 feet per minute, while the velocity of sewage in the outlet pipe under the same above conditions shall be at the rate of 210 feet per minute.

Each of the ejectors shall be provided with proper controlling valves, which shall be easily accessible and of such size that when passing the contract rate of flow, the velocity through the same shall not exceed 250 feet per minute. The whole of the valves shall be faced with dermatine attached by means of wrought-iron plate and delta metal set screws, and shall be so arranged as to be easily replaced when necessary. The corresponding valves of each ejector shall be interchangeable, and shall be attached to the valve seating with a delta metal hinge and pin.

Each ejector shall have one automatic air supply and exhaust valve with compressed air and exhaust pipes, sluice valves, siphon pipes, and one automatic air valve and all fittings complete. The alternating gear and valves shall be controlled automatically by the rise and fall of sewage in the receiver and shall be protected by suitable

arrangements from liability to choking through the influx of sewage, and the whole of the valves shall be of gunmetal.

The contractors shall also provide for the mouth of the inlet pipe in the inlet manhole a sluice gate with controlling gear to be worked from the road surface for the purpose of shutting off the sewage from entering the ejectors. Each ejector shall also be furnished with a six-figure counter of approved type.

The contractors shall also provide all wrought-iron and cast-iron pipe connections for the sewage and air mains inside the tubbing, the inlet pipes being complete from the inlet manhole, the discharge pipes terminating in a flange or socket joint at least one foot clear of the outer face of the tubbing, or, if the air vessel on the rising main is fixed outside the station, terminating at the air vessel, the compressed air supply pipes being carried one foot clear of the outer face of the tubbing, and the air, exhaust and ventilating pipes complete up to the outlet vent shaft. They shall also furnish a wrought-iron vessel and a reflux valve with flanged connections, to be placed on the rising main.

The contractors shall further provide pressure gauges to be fixed on the inlet air pipes inside the stations and a brass cock at lowest point of the exhaust pipes.

The contractors shall also provide a hand ejector or an air-driven donkey pump of a suitable capacity for discharging the water from inside the tubbing. The hand ejector or the donkey pump shall be fitted with the necessary pipes and fittings, and shall be capable of being worked from the surface of the ground. The cost of the hand ejector or the donkey pump, together with that of all the fittings required for the same, shall be held to be included in the rates for the main ejectors.

The whole of the pipes shall be of cast-iron and shall be tested at the contractors' works to a pressure of 100 lbs. to the square inch.

The whole of the flanges shall be properly faced and bracketted.

The receivers, valve boxes, etc., shall be coated inside and outside with Dr. Angus Smith's Composition.

The tubbing shall be of cast-iron built up in rings, the bottom ring to have a cutting edge formed on it to facilitate the sinking. The flooring shall consist of five plates strongly ribbed, of such size that they will pass through the entrance shaft, so that they can be fixed after the tubbing has been sunk in position. The entrance shaft shall not be less than 5 feet clear so as to allow of the floor plates and ejectors, etc., passing through. The tubbing, floor plates, and entrance shaft shall have internal flanges firmly bolted together and the joints made with lead pipe compressed between the flanges and caulked tight from the inside of the tubbing.

The whole of the iron work shall be erected at the contractors' works previous to the shipment and submitted to tests similar to the working conditions required for the same, and the whole shall afterwards be submitted to an air pressure of 60 lbs. to the square inch.

The castings shall be in loam and sound both externally and internally, and shall be carefully cleaned and dressed off. No portion of the castings shall be made in open sand, or from first runnings, nor otherwise than from metal, the tensile strength for which is less than 7 tons per square inch of section, or the transverse strength of which would be capable of sustaining for twenty-four consecutive hours a less weight than 7 cwts, placed in the middle of the length of a bar one inch square, supported

on points three feet apart. Test bars shall be provided, and from time to time tested at the contractors' works.

The wrought-iron shall be of good malleable quality and quite free from surface and shut or hammer marks or other defects, and the tensile strength shall be above 20 tons on the square inch.

The gunmetal shall be made of strong and durable mixture of pure copper and tin, no lead, zinc, or antimony being used therewith, and shall be wrought and fitted tc the several parts for which it is intended.

APPENDIX III.

GLOSSARY OF TERMS.

In all works on Engineering, and more particularly in these days of specialized branches of Engineering, many technical terms and names are used which are not usually found in Dictionaries. It is, therefore, deemed desirable, for the information more particularly of students interested in the special subjects with which this work deals, to give the meaning of such terms. Some are peculiar to certain districts in India, an example being *nahani*, a washing-place. another name for which is *mori*,—a word which is to a greater extent used outside the Bombay Presidency than within it. Certain it is that the meaning of many of the names used, though familiar to Sanitary Engineers in the East, would be quite unknown to Engineers practising in Europe; and therefore the Author hopes that this Glossary may be useful, not only to students interested in Sanitary Engineering, but even to Engineers generally. If some of the terms seem to be too simple and well-known to require definition, it should be remembered that English is a foreign language to many Eastern students, and it is to them that this work is also addressed.

ADJUTAGE ... ... Helper. The name given to a lip on the top of the inner leg of an automatic siphon, which helps the siphon to start flushing by allowing the water to fall over without touching the side of the leg.

Æration ... ... Impregnation with air or gas.

Ærobic ... ... "Living in contact with air." The term is applied to certain micro-organisms which live preferably in the presence of atmospheric oxygen and oxidize the ammonia in sewage into nitrites and nitrates. Ærobes are divided into facultative and obligate ærobes: the former can live in the absence of oxygen, the latter are unable to do so.

Alluvial ... ... The term applied to the soil and miscellaneous substances collected and deposited by the action of water.

Anærobic ... ... "Living without air." The term is applied to certain micro-organisms which live preferably without air. and reduce the organic matter in sewage, thus preparing it for treatment by ærobic bacteria.

Annular ... ... Having the form of a ring, pertaining to a ring.

Anti-siphonage Pipe. The term given to a small pipe which supplies air to siphons and traps, and prevents their being untrapped by a partial vacuum being formed through a sudden rush of water falling in a pipe to which the siphon or trap is connected.

Argillaceous Stone The class of stone in which alumina or clay is the characteristic constituent, such as slate and shale.

ARRIS ... ... Edge: a term often applied to bricks; for instance, it should be specified that bricks should have good sharp arrises, *i.e.*, sharp edges.

AUTOMATIC ... ... Having the power of self-motion; that which is self-moving, self-acting.

BACTERIA ... ... Bacteria is a generic term applied to a number of minute unicellular organisms belonging to the vegetable kingdom which multiply by fission only. The scientific term including all members of this group is Schizo mycetes or Fission-fungi. In this book the word bacteria is used generically to include micrococci and other members of this family.

BAFFLE WALL ... A wall built in a tank or channel to check the velocity of the flow.

BASALTIC ... ... A term applied to any substance derived from basalt—rock of volcanic origin.

BIOLOGICAL TANK ... A receptacle for liquid so constructed as to furnish to the micro-organisms contained therein the conditions most favourable to the efficient performance of their work in the direction of sewage purification.

BOARD OF CONSERVANCY. The body of men appointed to carry out measures for the preservation of health and cleanliness within a certain district.

BONING ROD ... ... A T-shaped piece of timber of a certain length, used in checking the levels of excavations or pipes.

BRIQUETTE ... ... A name derived from the French "Brique," a brick, and applied in Engineering to a small brick, made generally for testing purposes, as in cement testing.

BY-PASS ... ... An auxiliary passage by the side of a conduit or pipe.

CALCAREOUS STONE. The class of stone in which carbonate of lime predominates, such as marbles, lime stones, etc.

CAMBER ... ... A slight convexity or arching given to a road cross-wise to allow the surface water to drain off readily.

CAPACITY ... ... The quantity which a vessel is capable of containing or a channel of discharging. In case of sewers, the capacity is equal to the area of the sewer multiplied by the velocity.

CATCH-PIT ... ... A chamber built below the level of the invert of a sewer in which the velocity of the flow is reduced so as to collect such heavy deposit as may be in the sewage.

CENTRING ... ... The framing of timber by which an arch is supported during its erection.

CESSPOOL ... ... A receptacle for sewage: a chamber built to receive and temporarily hold sewage until it can be removed.

CHAIN-PUMP ... ... A pump consisting in one of its simplest forms of an endless chain equipped with a series of disks, passing downwards into the water and returning upwards through a tube.

CLINKER ... ... The incombustible portion of coal, partially fused, which forms in grates and furnaces.

COMBINED SYSTEM... The name given to the system of sewerage, in which the conduits are constructed for the double purpose of receiving both sewage and surface water.

CONFIGURATION ... The external aspect or contour of the land or district.

DASH-POT ... ... An apparatus for preventing the too sudden movement of parts. It usually consists of a small cylinder filled with oil and fitted with a piston through which a minute hole is drilled. The piston rod is attached to the part to be controlled.

DATUM ... ... Some fact or quantity granted or known from which other facts or quantities are calculated, *e.g.*, a certain step at the Town Hall, Bombay, is assumed to be 100 feet above an imaginary plane for the purpose of calculating other levels in the City.

DECANTATION... ... The act of pouring from one vessel to another, so as to separate one part of the liquid from another or to separate the liquid itself with matter in

suspension from matter precipitated in it, such as clay from sand, by putting the mixture into the water in a vessel, stirring it, and then pouring it off into another vessel; the liquid thus poured off carrying away the lighter particles of clay.

DEODORIZE ... ... To deprive anything of the fetid odour resulting from impurities.

DHAPA ... ... A slab stone used for covering or spanning a masonry drain.

DHOBI GHAT ... ... A public place used for washing clothes and sometimes belonging to and under the supervision of the local authority.

DIAPHRAGM ... ... *Vide* "Parda."

DISK-VALVE ... ... A circular sliding iron door used for closing a pipe sewer.

DOMESTIC SEWAGE... The sewage derived from the habitations of man and beast in contradistinction to that derived from factories.

DOUBLE DISK ... Two round blocks made principally of wood, fixed twelve inches apart and connected by bolts—an arrangement for passing through pipe sewers to cleanse the same.

DROP PIPE ... ... A vertical pipe joining two sewers at different levels in a manhole.

DRY SYSTEM LATRINE. A privy where fæcal matter and sullage are temporarily collected and afterwards removed by hand.

EJECTOR ... ... The name given by Mr. Shone to a spherically-ended container for receiving sewage, from which it is ejected by compressed air.

EXTRADOS ... ... The name given to the outside curve of an arch.

FAUCET ... ... That end of a pipe which is enlarged to receive the spigot end of another pipe to make a joint.

FILLET ... ... See "Splayed."

FLAP-VALVE ... ... A broad shutter made of wood or metal and hung over the face of a sewer and falling by its own weight and completely closing the sewer.

FLUSHING DOOR ... A flap which is let down by a hinge and closed over the face of a sewer or conduit to detain the sewage or liquid behind it, which, when opened, allows the liquid to flow away with a rush.

FÆCES ... ... The solid matter excreted by human beings: night-soil.

FOOT RESTS ... ... Raised surfaces in latrines or urinals to place the feet on, thus marking the exact place for the feet when either standing or squatting upon.

FORESHORE ... ... The sloping part of the sea shore between high and low tides.

GAMEL ... ... An iron pan for carrying materials generally of a semi-liquid nature, such as mortar.

GASKET ... ... A thin twisted or plaited rope of hemp put first into the joints of pipes to prevent the cementing material from passing through into the pipes.

GHÁNI ... ... An Indian term for a mill used in grinding mortar, the motive power being usually bullocks or buffaloes.

GRADIENT ... ... The name given in Sanitary Engineering to the inclination or slope of a pipe or conduit: the vertical fall divided by the horizontal distance.

GRAVITATION ... ... The act of tending to a centre of attraction, as when water flows from a higher to a lower level.

GROUT ... ... Cement mixed with water to the consistency of cream.

GULLY, GALI OR HOUSE-GULLY. A name given to a narrow open passage between houses, also called a sweepers' passage, as it affords access to sweepers and *halalkhores* to the latrines or privies of the house.

HALALKHORE... ... A class of people employed to remove by hand fæces, etc., from privies and dry system latrines.

HAUNCHES ... ... A term applied to the middle part between the crown and springing of an arch. In a semi-circular drain between the sewer and the side wall and the circular part of the drain.

HIGH-LANDS ... ... The name given to lands above high-water spring tides.

HUMID ... ... Moist, damp.

HUMOUS OR HUMUS.. Vegetable mould, or the matter deposited in a biological tank or filter.

HYDRAULIC ... ... A term relating to the conveyance of water through pipes or channels.

HYDRAULIC LIME ...	The term applied to lime which will set in the presence of water.
HYDRAULIC MEAN DEPTH.	The quotient obtained by dividing the area of the cross section occupied by the liquid by the wetted perimeter.
INLET	The term applied to the higher or upper end of a pipe or conduit.
INSPECTION CHAMBER.	A masonry chamber built to facilitate the inspection of a drain.
INTERCEPTING TRAP...	A trap or siphon placed on a house drain between the sewer and the house to intercept and prevent gas from the former passing up the drain or into the house.
INTRADOS	The name given to the inner curve of an arch.
INVERT	The name given to the lowest portion of a sewer, pipe, or drain.
JAGGERY...	Coarse brown (or almost black) sugar made from the juice of sugarcane or the sap of various palms, often seen in the form of small round cakes.
JOWAR	Indian name for millet.
JUMP-WEIR	A name given to an arrangement, made at the street end of a house-gully, which permits of a small flow of sullage from the gully to fall into a trap in connection with the house drain, but allows of a greater flow of surface water to pass over and discharge into a drain set apart for the purpose.

Kankar ... ... A class of hydraulic lime-stone, composed mostly of carbonate of lime, but also containing an admixture of clay and sand.

Khanki ... ... A stone fair-dressed on the face and rough-dressed on the other sides, fixed at the edge of a road bordering on an open drain, or used as facing in a stone building.

Kurbi ... ... Hindustani name for Indian corn or maize.

Lakh ... ... One hundred thousand.

Latrine ... ... A privy, or a place set apart for natural purposes. It may be either on the dry or water carriage system.

Lifting Gear ... An arrangement used for the raising or lowering of flushing doors by means of chains.

Liquefying Tank ... A tank in which the organic matter of sewage is broken up or liquefied by bacteria.

Loam ... ... A species of earth consisting chiefly of rich vegetable mould: a light earth or marl.

Low-lands ... ... The term applied to those lands which are situated below high-water spring tides.

Macadamize ... ... To cover a road with small broken stones, which, when consolidated, forms a firm surface. (From Macadam, the Inventor.)

"Mali" ... ... The Indian name for a gardener.

MANHOLE ... ... A masonry chamber built on a sewer or drain, through which it is possible to enter and have access to the sewer or drain for cleaning and inspection purposes.

MICRO-ORGANISMS ... In this book the word may be taken to mean bacteria. See "Bacteria."

MORI ... ... A place prepared with masonry and set apart or used for washing or bathing purposes, either inside or outside a house.

MURAM ... ... A local name given to the stratum of disintegrated rock lying between the clay and basaltic rock.

NAHANI ... ... See "Mori."

NIGHT-SOIL ... ... The solid matter excreted by human beings: fæces.

NULLAH OR NALA .. The Hindustani name for a watercourse: a rivulet.

OUTFALL ... ... The lower end of a sewer or conduit, or localities where the sewage or surface water is finally disposed of.

OUTLET ... ... The lower end of a sewer or conduit or the end through which the sewage is discharged from a manhole, tank, etc.

OVOID ... ... A term used to describe sewers built in the shape of an egg.

OXIDATION ... ... A term used in sewage purification to denote the final change which takes place in destroying organic matter: the addition of oxygen to the effluent by the admission of air to the latter.

Parda ... ... The name given to a stone slab fixed in the sides of a surface water gully so as to dip into the water and form a trap.

Pathogenic ... ... The name given to denote a class of organisms which, when introduced into the body, gives rise to diseases. (Pathogenic: disease producing).

Penstock ... ... A gate usually made of iron and built into the body, give rise to diseases. that it can be raised or lowered at will in controlling the discharge of sewage or water.

Plastic ... ... A substance capable of being moulded, used in patent jointed pipes to prevent the cement running into the pipe.

Plinth ... ... The masonry base of a building.

Plumb ... ... Vertical or straight.

Plumb-bob ... ... A weight attached to a string to test the uprightness or verticality of any object.

Pneumatic Sewer net. A term used in the Liernur method of drainage, to mean a series or network of pipes.

Pneumatic System.. The system in which vacuum or compressed air is the motive power employed for lifting sewage.

Poling Boards ... Boards intended to support the sides of a trench and placed behind the walings.

PRECIPITATION ... The process by which a substance held in suspension in a liquid is made to separate from another or others and fall to the bottom.

PRIVY ... ... A latrine.

PUBLIC CONVENIENCES. Places set apart for the convenience of the public, such as latrines, urinals, washing places, dhobi ghats, cab stands.

PUDDLE ... ... Clay worked up by being mixed with water to a plastic or sticking condition.

PUMICE STONE.. ... A porous stony substance of volcanic origin.

PUNNED ... ... Rammed: packed tight by pounding.

RENDERED ... ... Made smooth: plastered in cement.

ROAD DETRITUS ... The term used to denote the small particles of disintegrated stone, etc., worn off from the surface of the roads by traffic.

RUBBLE ... ... Rough irregular stones used in coarse masonry or to fill up between the facing courses of masonry.

SCRAPER, OR SHIELD. An appliance used in cleaning an ovoid sewer and made in the shape of the sewer with a portion of the bottom or the top cut off; when inserted in the sewer it heads up the sewage by contracting the area of the flow, which is consequently accelerated and facilitates cleaning by softening the deposit.

Screen ... ... A riddle or sieve used to separate fine matter from coarse, either solid or liquid.

Scum-board ... ... A board placed across, and descending six to eighteen inches below the surface of the fluid in a tank, to check the flow and thereby arrest the floating matter.

Seal ... ... The depth of contained water in a trap which prevents the free passage of air or gas through it.

Sectional System... The name given to the system of sewerage in which a district is divided into sections, each of which has sewers gravitating to one point within it.

Separate System... The name given to a system of sewerage, in which there are different conduits for storm-water and sewage.

Septic ... ... A term denoting the promotion of putrefaction.

Set Stone ... ... A medium dressed stone used for paving purpose in places liable to heavy traffic.

Sewer ... ... A conduit for sewage.

Sewage ... ... The filthy liquid containing excrementitious and other matters from houses and towns which passes through drains.

Shored ... ... Propped or supported by timber.

SIGHT RAILS ... ... Rails about 4 inches by 2 inches fixed across an excavation on wooden posts with their tops at a certain height above the intended level of the bed of the sewer. A line of sight along the tops of the rails so fixed would be parallel to the gradient of the sewer.

SILICEOUS STONE ... A class of stone in which silica or sand is a characteristic constituent, such as granite, trap, basalt, etc.

SILT ... ... A term given to the deposit of solid matter found in sewers and drains.

SIPHON ... ... A bent tube whose legs are of unequal length, used for drawing liquid out of a vessel, the shorter leg being inserted in the liquid and the larger hanging down outside; when the air is sucked from the tube the pressure of the atmosphere causes the liquid to rise in it and flow over.

SIPHONAGE ... ... The action or operation of a siphon.

SLUDGE ... ... Soft mud: the term applied to the deposit in biological tanks and filters.

SLUICE ... ... A contrivance for excluding or admitting the inflow of a body of water.

SOCKET ... ... The opening at the end of a pipe generally enlarged, into which is inserted the end of another pipe to make a joint. See "Spigot."

SOIL PAN ... ... A receptacle fixed in a latrine or a water-closet, to receive fæcal matter.

SOIL PIPE ... ... A vertical pipe fixed against a wall to take the discharge from water-closets.

SPECIFIC GRAVITY... The weight of the bulk of any substance compared with that of the same bulk of water.

SPIGOT ... ... The end of a pipe which is inserted into the enlarged end of another pipe to make a joint.

SPLAYED FILLET ... A narrow band of cement used to complete the joint of a pipe and having a sloped surface.

STRATUM ... ... A layer or bed of stone or earth. Strata (the plural), several such layers superposed above each other.

STERILIZATION ... By the expression sterilization of any substance is meant destruction or removal of all germs and their spores contained in or on such substance.

STREET CONNECTION. That part of the house drain which lies between the street sewer and the boundary of the house.

STOP TAP ... ... The name given to a cock used in connection with an Adam's time siphon.

SUBSOIL ... ... The beds or strata which lie below the surface soil.

SULLAGE... ... ... The liquid and other matters discharged from bath, cook-room, etc., and not containing excrement.

SUMP ... ... A reservoir or pit below a pump: the lowest point.

SURKI ... ... A fine powder made by crushing burnt brick.

TANK GAS ... ... The gas that is liberated in a liquefying tank, while the organic matter of the sewage is broken up or liquefied.

Tensile Strain ... The elongation per unit of length resulting from a tensile stress.

Tidal-flap ... ... A door attached to a sewer at a manhole, by which the sewage may be retained in the sewer for flushing purposes (properly, a gate used to exclude tidal water).

Trapped ... ... So formed as to hold a depth of water sufficient to prevent the free passage of air or gas.

Trade Sewage ... Sewage derived from factories containing chemical matter.

Tubbing ... ... A water-tight cast-iron chamber constructed underground to contain an ejector or ejectors.

Tufa ... ... A light porous rock of volcanic origin.

Urban ... ... That part of a large city or town which has been fully built upon.

Velocity ... ... The rate of movement or flow: the distance traversed in a given time, usually expressed in feet per second or per minute.

Vent Pipe ... ... The pipe connected with a sewer or drain to maintain an equilibrium of pressure between the outside air and the inside air of a sewer and to allow of the discharge of the sewer air into the open air, or the admittance of outside air into the sewers.

Ventilate ... ... To create a current of fresh air through a sewer or drain so as to cleanse it of foul air.

VOUSSOIRS ... ... Wedge-shaped stones or blocks of concrete used in constructing an arch.

WALING .. .. A piece of timber placed horizontally to support the sides of a trench.

WASH-DOWN CLOSET. A latrine on the water carriage system, the soil pan of which discharges downward into the trap.

WASH-OUT CLOSET... A latrine on the water carriage system, the soil pan of which discharges horizontally into the trap.

WASTE WATER PIPE. A vertical pipe used for the discharge of sullage.

WATER CARRIAGE LATRINE. A privy, the fæces from which are carried to the sewers by water.

WATER CLOSET ... A latrine on the water carriage system.

WATER GULLY ... A trapped receptacle through which the surface water from the road flows into an underground drain.

WATER TABLES ... Flat dressed stones fixed at the sides of a road over which the surface water from the road flows to the water gully or drain.

WETTED PERIMETER. The length (measured at right angles to the flow) of such parts of the sides and bottom of a conduit or channel as are in contact with the liquid.

WINDSAIL ... ... A tube or funnel of canvas used to convey air into sewers or drains.

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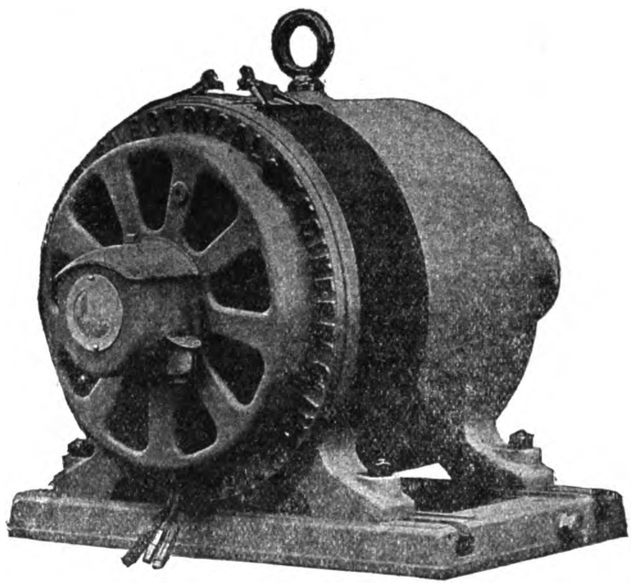
APPENDICES.



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